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FEATURES

Gas Carburization of Steel—

R. G. Guthrie and Dr. O. J. Wozasek 853

On the Constitution and Properties of Hardened Steel—

W. P. Sykes and Dr. Zay Jeffries 871

Segregation of Dissolved Elements and Its Influence upon
Carbon Distribution in Steel—

E. G. Mahin and H. J. Dillon 905

Recent Experiments Relating to the Wear of Plug Gages—

H. J. French and H. K. Herschman 921

Forging Machine Die Design for Deep Piercing— *E. R. Frost* 954

Relationships Between Rockwell, Brinell and Scleroscope
Numbers—

R. R. Moore 968

Notes on the Spark Testing of Steel—

George M. Ewos 976

Preparation of Aluminum Oxide for Final Polishing and the
Preservation of Polished and Etched Surfaces—

W. P. Fishel 982





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AGATHON ALLOY STEELS

TRANSACTIONS

American Society for Steel Treating

VOL. XII

DECEMBER, 1927

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GAS CARBURIZATION OF STEEL

BY R. G. GUTHRIE AND DR. OSCAR WOZASEK

Abstract

The paper deals with use of so-called city or manufactured gas for a carburizing medium and considers certain inconsistencies heretofore encountered in its use. The research work set forth was undertaken to determine ways and means for controlling the process of carburizing with gas and as such considers (1) variation in depth and concentration of case from day to day (no variation has been encountered within a single charge), (2) what constituent in gas is responsible for the carburization of steel, (3) what is the mechanism of carburization, (4) what are the factors affecting this mechanism? All tests were duplicated on five different types of commercial carburizing steel. Results show advantages to be gained from treatment of carburizing gas at the furnace, and catalyzing the steel in the furnace at the beginning of the run.

THE use of so-called city or manufactured gas for the carburization of steel has presented some problems of a complicated and little known nature to both gas companies and users. The gas in question is one such as the mixed gas that is regularly supplied for domestic and industrial purposes in the city of Chicago with calorific value of 536 B. t. u. per cubic foot and a typical analysis as follows:

	Per Cent		Per Cent
Carbon Dioxide	2.8	Hydrogen	47.2
Illuminants	4.2	Methane	22.4
Oxygen	1.0	Nitrogen	11.4
Carbon Monoxide	11.0		

A paper presented before the ninth annual convention of the society held in Detroit, September 19 to 23, 1927. Of the authors, who are members of the society, R. G. Guthrie, is metallurgist, industrial gas department of the People's Gas Light and Coke Co., and Dr. O. J. Wozasek is research chemist with the same company. Manuscript received August 15, 1927.

The product supplied consists largely of a coke-oven gas which is augmented during the peak load periods with a carburetted blue water gas of about the following composition:

	Per Cent
Carbon Dioxide	1.0
Illuminants	8.2
Oxygen	0.6
Carbon Monoxide	34.6
Hydrogen	31.4
Methane	16.2
Nitrogen	8.0

In general the resultant gas is of the composition shown in the first analysis. Carburization with this gas is carried on by heating the steel in containers in either a rotary retort or stationary pit type furnace and allowing a steady flow of unburned gas to go through the retorts in the rotaries from back to front and in the pit type furnaces from bottom to top.

From the economic as well as the quality standpoint, this is no doubt the most successful carburizing method available in spite of the fact that very perplexing problems and inconsistent results are sometimes encountered when using it. It was for these reasons that The Peoples Gas Light & Coke Co. decided to undertake a research to discover a remedy if possible for these difficulties. The results have been, we feel, highly satisfactory. The mass of technical information and data accruing during this research is much too large to be incorporated in this paper. We shall attempt to set forth in as brief and non-technical way as possible the purposes for which this research was decided and summarize our results in the same manner. Later the complete results will be published in all their technical detail and distributed in the form of a brochure.

The problems in the order of their importance are:

1. Variation in depth and concentration of case from charge to charge or day to day. No variation has been encountered in different parts of the same charge.
2. What constituent is responsible for the carburization of steel?
3. What is the mechanism of carburization?
4. What are the factors affecting this mechanism?

By carefully watching a practical production operation having a capacity of about 6000 pounds of parts per day, it was noticed

that operating at 1675 to 1725 degrees Fahr. and a pressure on the carburizing gas of 15 pounds per square inch, a case of 1/16 inch was obtained under the best conditions in about 6 to 8 hours (carburizing time). The pieces averaged from 10 to 300 pounds each. The minimum section was 1 inch. The variations between top and bottom of the retort and side and center were not practically measurable. This condition prevails for as long as eight or nine months without appreciable variation in comparatively new nickel-chromium alloy retorts.

However, suddenly without any apparent reason and with no changes in the mode of operation and using the same steel, it became impossible to obtain the desired penetration in less than 17 to 20 hours of carburizing time.

Obviously, the first problem was to minimize this great variable even at the expense of more rapid penetration. We attributed part of the trouble to water, and as a remedy dried all the gas going into the retort by passing it over calcium chloride. Immediately this great difference between maximum and minimum time for a given case disappeared and in its place a practically constant time was obtained, which was longer than the minimum, but less than the maximum. The time intervals with the dehydrated gas are 10 hours minimum, 12 hours maximum. The next step was, of course, to determine, if possible, why a gas of given composition at one time gave such a rapid case while at others apparently the same gas gave practically no case at all.

During the investigation of the wet gas at various temperatures on five representative classes of iron and steel, it was found that about 1700 degrees Fahr. was a very critical temperature and that the curve for increased penetration for increased temperature broke at about 1700 degrees Fahr. and a partial decarburization occurred. With the dehydrated gas no such point is found between 1400 and 1800 degrees Fahr. A peculiarity of the dehydrated gas is that the heating time of the retort is slightly longer than with the wet gas. This is explained by the higher thermal conductivity of the gas.

During the laboratory tests that follow some 275 samples were investigated in some 60 to 65 separate and complete tests or runs and a special method of application of the gas to the heated sample was evolved. It was found on the first runs that the sample nearest

the inflow of gas gave the best results. In these tests five representative types of iron and steel were used simultaneously in each test as follows:

(1) Armco iron, (2) standard S. A. E. 1020 basic open-hearth steel bought at random, (3) standard open-hearth screw stock bought at random, (4) guaranteed carburizing steel S. A. E. 1020, and (5) the steel having the trade name of Jalcase.

These samples were heated within a 2½-inch fused silica tube and were evenly spaced apart. A second fused silica tube was inserted with the first. This second tube, closed at one end, had five holes in the side, each hole being directly in front of its respective sample. The gas was introduced in this first tube, passed through the hole directly over the samples and into, through and out of the second tube. Analyses were made of the gas before it entered and after it left the tube. Temperature curves were also prepared for both heating and cooling.

In each test all of the conditions such as time, temperature, volume of gas, velocity of gas, pressure, barometric pressure, analyses of gas before and after the steel, heating and cooling were very carefully kept the same in every instance. The samples were all lathe-turned with the same tool at the same speed and feed. The weighing was all done upon a special balance sensitive to 1/100 milligram with a 40-gram load.

The laboratory results are all interpreted in milligrams of increased weight and are carried to the fifth decimal place. For convenience, however, the increase in weight when referred to will be in milligrams.

Finding that the most of the variables could be removed with the removal of the moisture in the gas and that the carburizing time dropped from 17-20 hours to 10-12 hours, the next problem was to determine by gas analyses the difference between so-called bad gas which gave no case to speak of and so-called good gas that gave a very heavy case.

The surprising fact was then disclosed that from gases that analyzed practically identical in a Moorehead burette, good and poor results were obtained, not in one instance only but in every one. For a check on gases in general, a well-known barium-energized compound was used and the gas evolved passed over the samples. The results furnished a standard to work to. At 1600

degrees Fahr. the compound gas gave increases in weight of about 30 milligrams, whereas our bad gas gave from 1 to 20 milligrams difference in weight. Gas taken during normal runs which gave good average results in practice, yielded samples of an increase of about 30 to 40 milligrams.

Two analyses of so-called bad gas and a good average gas are compared below :

	Good Gas Per Cent	Bad Gas Per Cent
Carbon Dioxide	2.8	0.4
Illuminants	4.2	3.2
Oxygen	1.0	0.4
Carbon Monoxide	11.0	10.5
Hydrogen	47.2	45.4
Methane	22.4	20.1
Nitrogen	11.4	20.0

A careful comparison of these two gases will not reveal any reason why the good gas gives a 1/16-inch case in about 10 hours and the bad gas gives the same case in 20 hours, other conditions being identical, nor will any clue be found by a comparison of these gases with the average gas evolved from compound as the compound gas is less rich than either of these two.

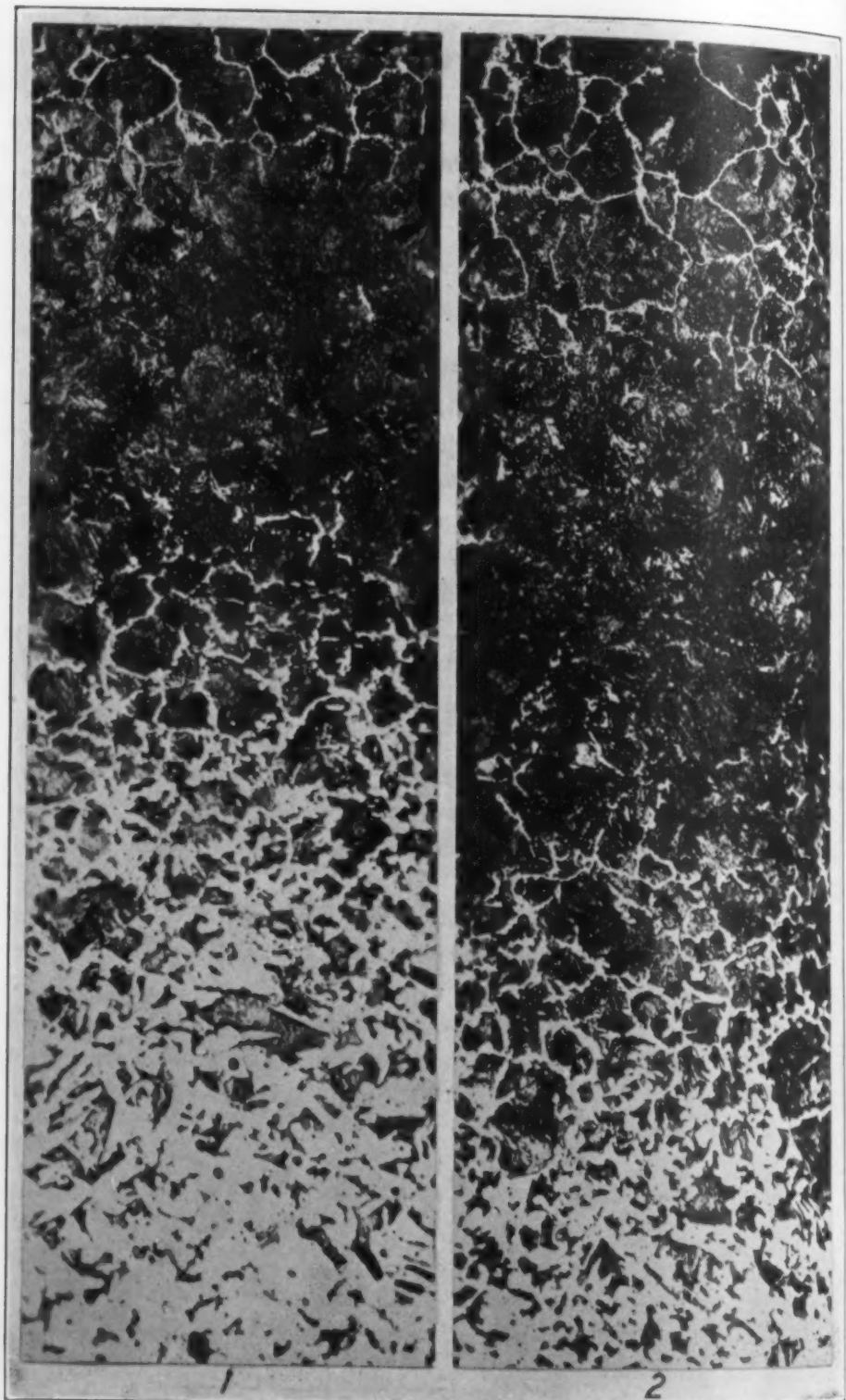
At this time it was found that gas is far more sensitive to carburization than it is to any analysis yet worked out. Our iron, oxygen and carbon hypothesis was then evolved, and this hypothesis, which is too lengthy to reproduce here, gave the necessary clue to the solution.

In tests 54 and 52, the practical demonstration of the evolved theories was made and alone proves them, but still other tests confirm them in their entirety.

In test 54, a carburetted blue water gas was used, the composition of which is shown below. The five samples of steel were run at 1600 degrees Fahr. and gave the following increases in weight:—

	Per Cent		Milligrams
Carbon Dioxide	1.0	Armco Iron	53
Illuminants	8.2	S. A. E. 1020	8
Oxygen	0.6	Screw Stock	38
Carbon Dioxide	34.6	Guaranteed S. A. E. 1020..	2
Hydrogen	31.4	Jalcase	1
Methane	16.2		
Nitrogen	8.0		

Gas of identical analysis was then used, but with the introduction of a very minute percentage of oxygen in excess of that



Figs. 1 and 2—Photomicrographs of Specimens from Test 54 and Test 52 Respectively, Screw Stock Carburized. Mag. 125 x. See Table I for Data Regarding All Photomicrographs in This Paper.

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shown in the analysis. This oxygen was introduced by simply changing a drying U-tube a little after the start of the run. The results were astonishing. Figs. 1 and 2.

	Milligrams
Armeo Iron	85
S. A. E. 1020	68
Screw Stock	96
Guaranteed S. A. E. 1020	88
Jalcase	87

A city gas was then used having an analysis of test 38 as shown below. Again the temperature was 1600 degrees Fahr. and the increase in weights were:

Per Cent	Milligrams
Carbon Dioxide	1.4
Illuminants	2.6
Oxygen	0.6
Carbon Monoxide	9.0
Hydrogen	45.0
Methane	23.9
Nitrogen	17.3

See Fig. 3

Table I

Data Regarding Photomicrographs

This data applies equally to all photomicrographs illustrating this paper.

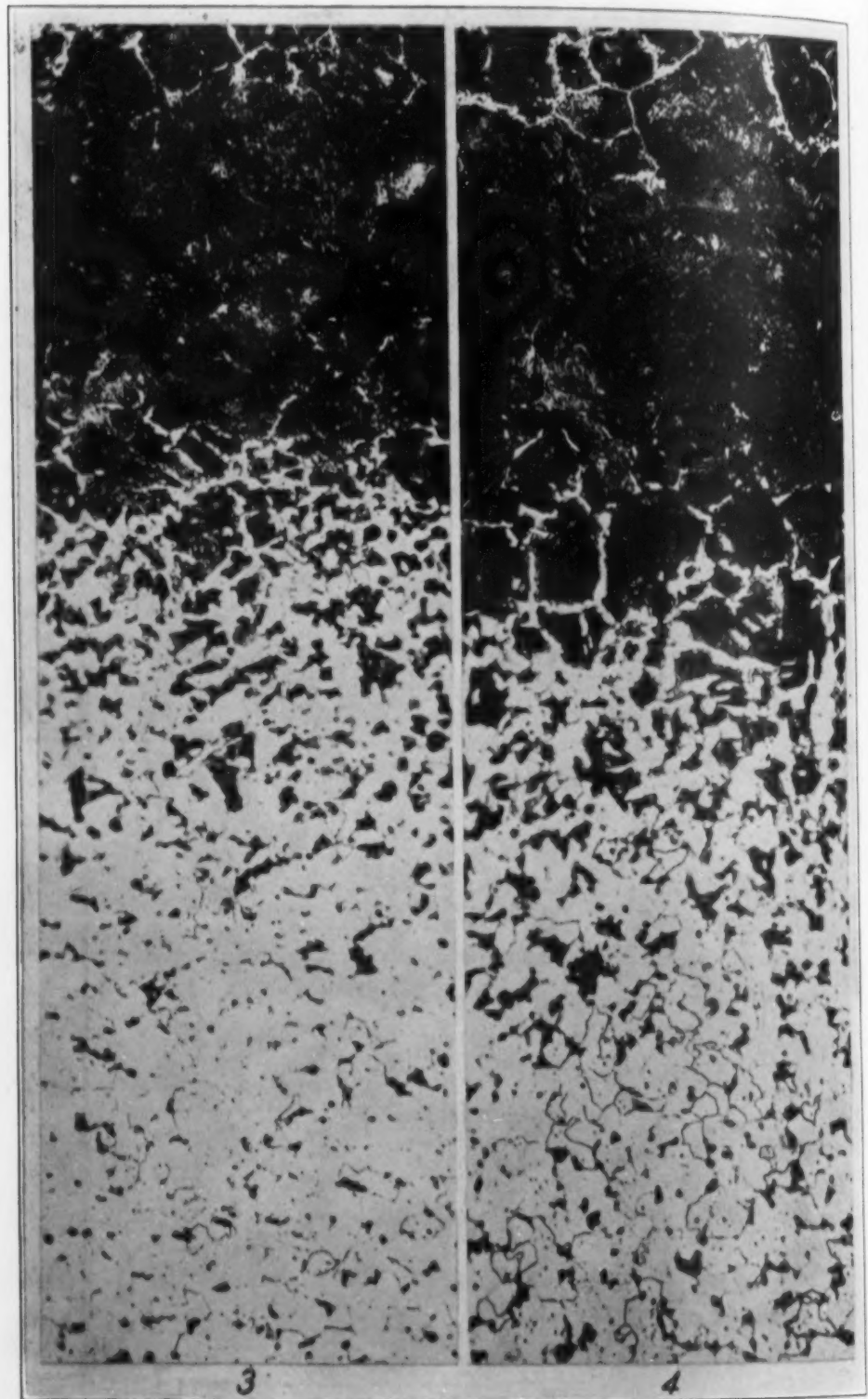
ETCH: Nitric Acid in Glycerine.	OBJECTIVE: 14-millimeter achromat.
INSTRUMENT: Leitz Micro-Metallograph.	OCULAR: 4 x Periplan.
VIBRATION ABSORBERS: Brake.	CAMERA EXTENSION: 50 centimeters.
ILLUMINATION: Arc.	EXPOSURE TIME: 20 seconds.
FILTER: Wratten B.	PLATE: Wratten M.
1ST IRIS: 5	SIZE: 6½ x 8½ inches.
2ND IRIS: ½ open	DEVELOPER: Pyro-Soda.
RACK POSITION: 1 mm. up.	TEMPERATURE: 70 degrees Fahr.
ILLUMINATOR FOCUS: center.	TIME: 1½ minutes.
ILLUMINATOR: Prism.	MAGNIFICATION: 125 x

The same gas was again used as in test 54, but with 2 per cent carbon dioxide added continuously during the run with the resultant increase in weights of:

	Milligrams
Armeo Iron	40
10-20 S. A. E. 1020	50
Screw Stock	53
Guaranteed S. A. E. 1020	42
Jalcase	43

See Photomicrograph Fig. 4

Samples were then treated in pure carbon dioxide and gave the peculiar crystals common to the beginning of all scale as shown in Fig. 5.



Figs. 3 and 4—Photomicrographs of Samples from Test 38 and Test 40 Respectively. Screw Stock Carburized. Mag. 125 x. See Table I.



Fig. 5—Photomicrograph of the Surface of Armeo Iron After Treating with Carbon Dioxide. Mag. 125 x. See Table I.

Whether this formation is Fe_3O_4 or not cannot be positively said at this time, but the following evidence together with other data and our iron-oxygen-carbon hypothesis indicates that this scale or crystal formation is not Fe_3O_4 , and that carburization of iron or steel cannot be successfully carried on without its formation as a catalyzer to the actual absorption by the iron of the carbon. In substantiation test 57 was run of a so-called bad gas of the composition,

	Per Cent
Carbon Dioxide	1.0
Illuminants	2.8
Oxygen	0.4
Carbon Monoxide	8.6
Hydrogen	45.0
Methane	25.4
Nitrogen	16.8

to which was added in the inlet line, 25 minutes after the run began, a U-tube of calcium chloride, into which had been run as much carbon dioxide as would remain in and around the calcium chloride. The results with this gas alone were never more than 1 milligram increase in weight, but with the carbon dioxide added at the beginning of the run only, the increased weights were:

	Milligrams
Armco Iron	87
S. A. E. 1020	76
Screw Stock	85
Guaranteed S. A. E. 1020	88
Jalcasc	92

See Photomicrograph Fig. 6

Further substantiation was obtained in test 51 in which a bad city gas of the composition,

	Per Cent
Carbon Dioxide	0.3
Illuminants	3.1
Oxygen	0.4
Carbon Monoxide	8.7
Hydrogen	46.8
Methane	23.6
Nitrogen	17.1

was used and the carbon dioxide extracted again. This gas was only capable of increasing the weight of the samples about 1 milligram, but oxygen was added once to the run by changing a U drying tube with the result that the weights increased as follows:

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	Milligrams
Armeo Iron	98
S. A. E. 1020	61
Screw Stock	76
Guaranteed S. A. E. 1020	78
Jalcase	78

See Photomicrograph Fig. 11

To further prove the contention that the steel must be first oxidized with these crystals even very minutely before carburization can take place, a bad city gas was used upon four small samples and one large or standard one. The gas of the analysis:

	Per Cent
Carbon Dioxide	0.4
Illuminants	3.2
Oxygen	0.4
Carbon Monoxide	10.5
Hydrogen	45.4
Methane	20.1
Nitrogen	20.0

was put over the samples which were all of the same bar (Jalcase No. 5). The samples this time were treated by oxidizing two of them after polishing and two were polished only. The standard 40-gram sample from the same bar was oxidized. This gas normally with unoxidized samples only adds about 1 milligram of weight under the conditions, but with the three oxidized samples in the furnace, increases were noted in all samples as follows:

Polished only—weight increase on 20-gram samples were 55 on one and 57 milligrams on the other.

Polished and oxidized in an open gas flame—increase in weight for the sample oxidized dark brown was 61 milligrams. The one oxidized dark blue—increased 62 milligrams on the 20-gram samples. The 40-gram sample also oxidized gave an increase of 87 milligrams due to its larger size.

The above would at a glance seem incongruous, but when it is remembered that only very minute quantities of oxygen as proven in the foregoing are required, it is obvious that the oxidized samples being in the same retort with the unoxidized ones supplied the amount necessary to bring about these large weight increases with a gas otherwise incapable of any increase.

Figs. 6 to 10 inclusive show the reactions of the five classes of iron and steel to a bad gas treated with a minute quantity of

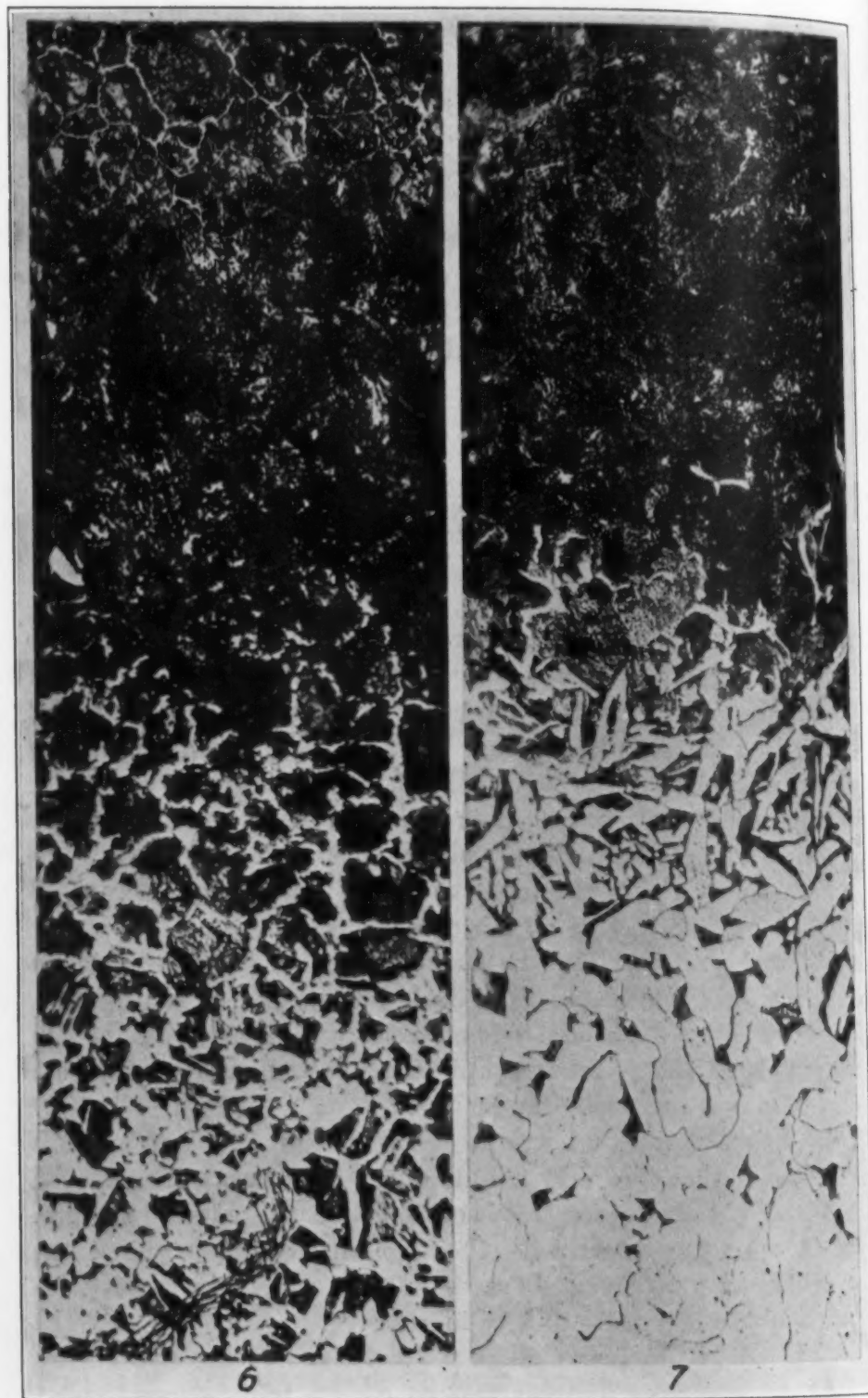
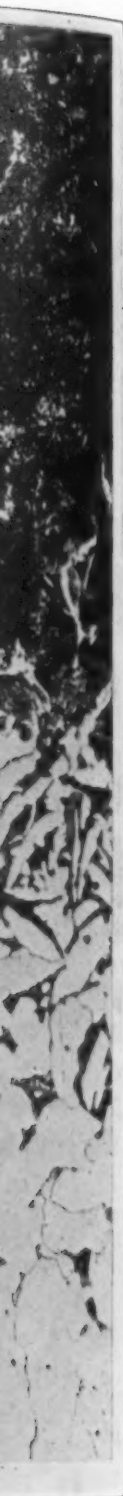


Fig. 6—Photomicrograph of Sample from Test 57, Screw Stock Carburized. Fig. 7—Photomicrograph of Sample from Test 57, Armco Iron Carburized. Mag. 125 x. See Table I.



ed. Fig. 7—
See Table I.

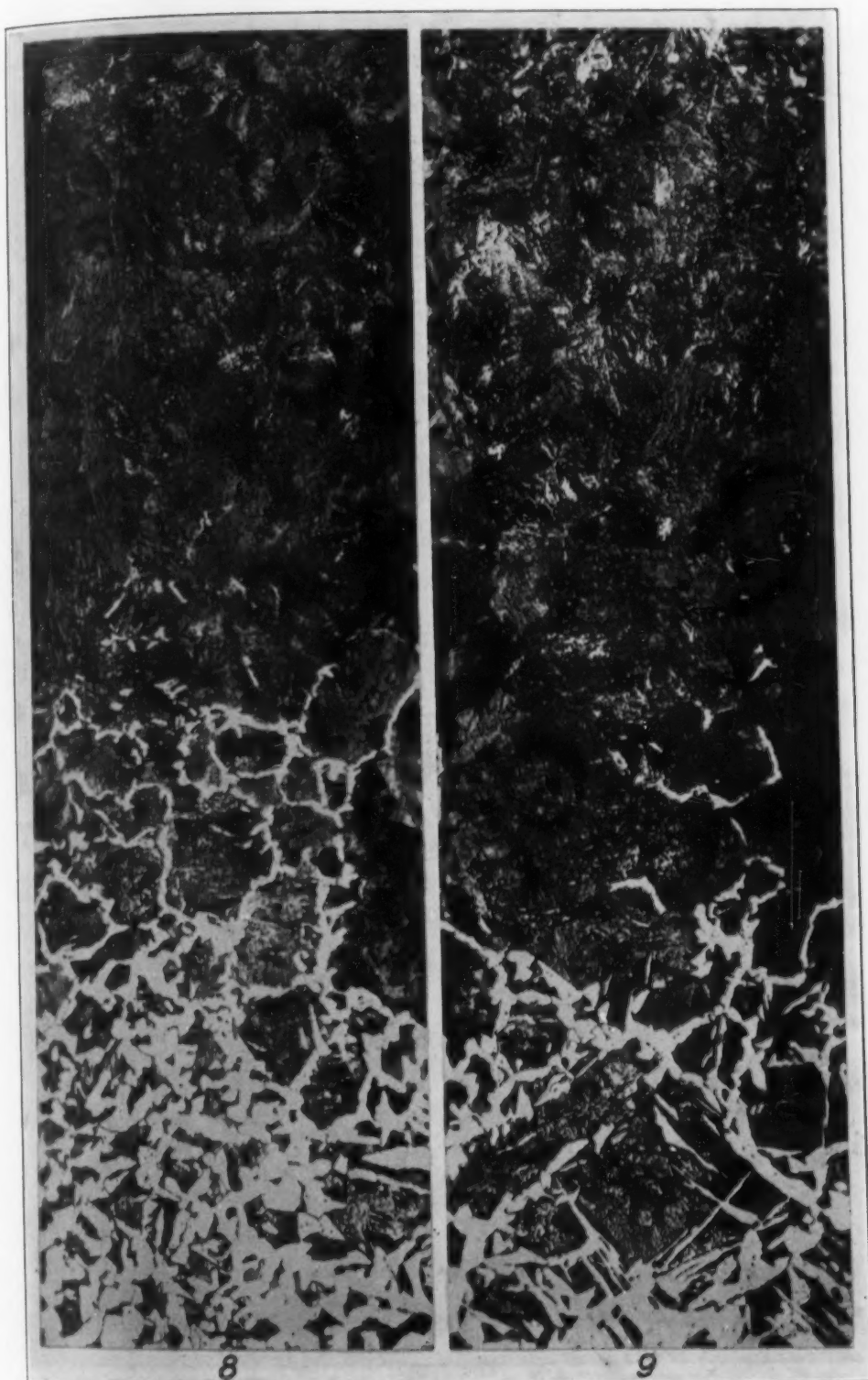


Fig. 8—Photomicrograph of Sample from Test 57, 1020 S. A. E. Steel Carburized.
Fig. 9—Photomicrograph of Sample from Test 57, Guaranteed Normal Steel Carburized. Mag. 125 x. See Table I.

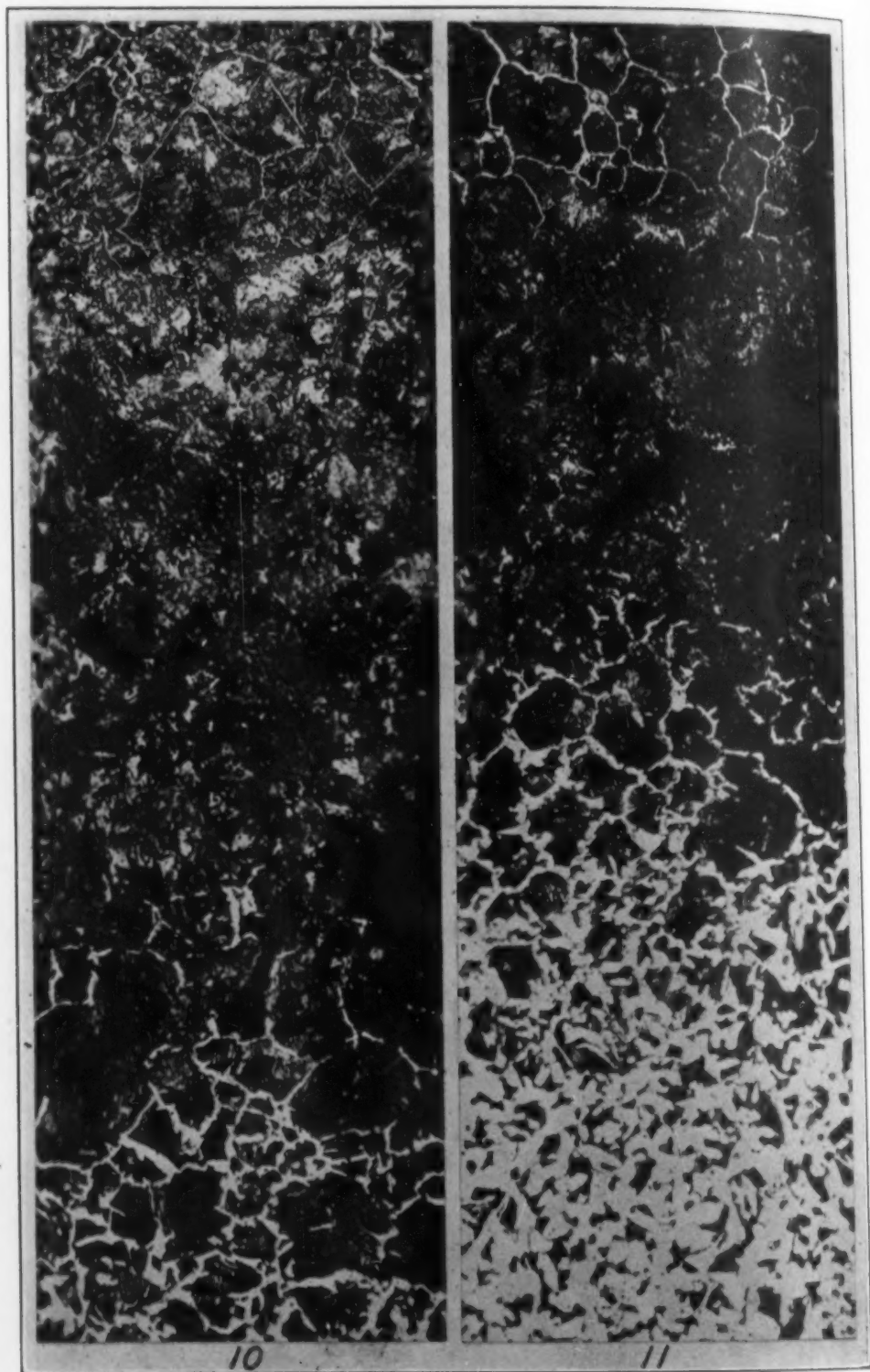


Fig. 10—Photomicrograph of Sample from Test 57, Jalcase Carburized. Fig. 11—Photomicrograph of Sample from Test 51, Screw Stock Carburized. Mag. 125 x. See Table I.

carbon dioxide. These samples are representative of results obtained in practice at 1600 degrees Fahr.

A further run was made at 1600 degrees Fahr. in which the above bad gas was used, but first the samples were brought up to heat and 35 cubic inches of wet or water-saturated gas was put over the test pieces, the bad gas (dried) was then allowed to continue the run with the result that again increases as follows were obtained:

	Milligrams
Armco Iron	76
S. A. E. 1020	72
Screw Stock	81
Guaranteed S. A. E. 1020	80
Jalcase	83

Therefore it is apparent that by applying oxygen to the gas or the steel in four different forms, essentially the same results are obtained, and these results far exceed those obtained with what we know as good gas or compound gas.

A peculiar phenomena has been observed by us for many years. In carburizing in new nickel-chromium retorts using compound, a satisfactory case is obtained at 1600 to 1700 degrees Fahr. However, if the work is quenched, it will be found to be hard all over, but if it is returned to the retort at 1425 degrees Fahr. or thereabouts for a reheat and compound again put in ostensibly to eliminate oxygen, the pieces upon quenching are found to have a thin decarburized skin over them. We now believe that new or uncarburized nickel-chromium alloy is capable of transmitting oxygen at these low temperatures and inasmuch as the gas in attempting to establish a state of stable equilibrium has a higher affinity for the carbon than the steel does to satisfy the oxygen breathed in by the retort. This trouble always disappears after the retort has been used for a week or so. At times for carburizing, we have received our best results in practice when the retorts were new.

In conclusion, therefore, we feel safe in saying that oxygen in any one of several forms is an absolutely necessary constituent. That the various unsaturated hydrocarbons act very differently during carburization as we have investigated the effects of benzol, gasoline, naphthalene, acetylene, ethelyene, etc., and are now carrying this investigation much further than has been reported in this paper, and we feel that a great deal of valuable information will result regarding the behavior of iron and steel in the presence of

1—Photo-
Table I.

the various carbons, hydrocarbons and their combinations. In coal gas the illuminants consist of approximately 2 parts of ethylene to 1 part of benzol and in a total 3 per cent illuminants sufficient available carbon for carburization may be obtained at very low price even with gas at \$1.00 per thousand cubic feet. As previously stated, this work has only begun, but in its beginning has borne successful practical results which more than justify its continuance.

DISCUSSION

M. L. FREY: I should like to ask Mr. Guthrie under what pressure this gas was supplied to the retort.

R. G. GUTHRIE: Fifteen pounds per square inch.

M. L. FREY: That is, your so-called bad gas was still bad when the pressure was increased?

R. G. GUTHRIE: Yes, at any pressure that we ran it, and we ran up to to as high as 15 pounds per square inch.

M. L. FREY: Was there any noticeable improvement in results obtained from the bad gas as you increased the pressure?

R. G. GUTHRIE: No, not noticeable, at least. I think I understand the point you are making, that is, like abnormal steel; sometimes it is more abnormal than others, and your point is that sometimes this gas is worse than others, and when it is not quite so bad, we will say, then the increase in pressure does help.

M. L. FREY: In case you have a so-called good gas, will it carburize at the normal pressure which is supplied, say 6 inches of water?

R. G. GUTHRIE: Yes, it will carburize at that pressure, but not with the speed that it will at the higher pressures.

M. L. FREY: The reason I asked that is because we are using carbureted water gas as a carburizing agent, and we find that it gives us no results when supplied under normal pressure. As soon as we increase the pressure to 12 pounds, we get very good results, and apparently very consistent results.

R. G. GUTHRIE: It would be interesting for you, having had that experience with this gas at 6 inches or 4 inches of water, to go ahead and try this with 15 pounds pressure. We have tried it, and we get a very rapid increase in weight.

M. L. FREY: I would also say that this water gas that we are using gives a very heavy deposit of soot at all times.

R. G. GUTHRIE: Then you need this, because a heavy deposit of soot is proof of that part of it.

A. W. SCHLUETER: Mr. Guthrie made some reference to stationary and rotating retorts. I should like to ask him if he found that the stationary retorts gave an even case.

R. G. GUTHRIE: Yes, we have. I do not like to pass this question on, but I can, because the maker of the retort is sitting right there and he can tell you about it. We find by taking a series of bars that are the full length of the

height of the inside of the retort and placing them in there in various positions with respect to the diameter of the retort, we get the same case in all parts of the furnace. Whether the gas is bad and we have bad results or whether the gas is good and we have good results, the results are practically uniform. That comes as a result of the construction of the furnace, the baffles in the retort, etc., that are necessary to distribute this gas. Now, in carburizing heavy gears, I think Mr. Taylor will bear me out that the gears have the same case, the one on the bottom, for instance, will have the same case as the one in the middle or the one on the top, even where they are practically the diameter of the retort, as will be true also in the case of gears that are only, we will say, one-tenth of the diameter of the retort and therefore are put in a circle, or two layers.

A. W. SCHLUETER: In the rotating retort, were the pieces fixed or were they tumbling?

R. G. GUTHRIE: They were tumbling. The rotating retort, however, gives a different set of conditions, I should say, almost entirely different from the stationary retort, but not in reference to the uniformity of the product. The customers who have used those furnaces have never, to my knowledge, reported any non-uniformity in the furnace, it is just non-uniformity from day to day in any case that they get, which the gas is responsible for.

QUESTION: Have you used calcium chloride to dry the gases?

R. G. GUTHRIE: We have used calcium chloride and we have used some of the unsaturated hydrocarbons.

G. A. UHLMAYER: In regard to the statement you made that gases having the same apparent chemical analysis may differ widely in the results produced when used for carburizing, you have termed them "good" and "bad" in so far as the results are concerned. It is not clear in my mind whether this is a question of moisture content of the gas or some other cause. Will you please explain?

R. G. GUTHRIE: No, the question is the type of hydrocarbon that is in the gas. They are both analyzed as unsaturated hydrocarbons, or illuminants, so-called, by the Morehead burette, but it depends upon the type, or where those hydrocarbons came from. In carburized blue water gas you have the hydrocarbons coming from oil, while in the coke oven gas you have them coming from tar. It depends on whether they are from the ethylene side or the acetylene side and the proportion of that particular hydrocarbon to this CO_2 . One may be worse than the other, but they analyze, according to ordinary technical methods, as illuminants. But, irrespective of what they come from, or whether they are formed at high or low temperatures, in our experience, which consists of having run between 75 and 100 actual tests on them, the water vapor or the CO_2 or oxygen in any form apparently takes care of that. Now, if they do not need that and it is put in there, that ratio is built up between the CO_2 and the unsaturated hydrocarbons, it does not hurt them any unless you get sufficient water vapor in to begin to decarburize the sample later on in the run.

G. A. UHLMAYER: I have always been under the impression that the carbon monoxide content of the gas used for carburizing was the important

factor as far as satisfactory results are concerned. What have you found in this regard?

R. G. GUTHRIE: We can not find that it does. It undoubtedly would if you took the unsaturated hydrocarbons out. Then the saturated hydrocarbons would start to work; and if you took the saturated hydrocarbons out, apparently the CO would be the thing that had to do it, if it did it at all. We find that we have practically the same CO, as you will see in nearly every instance the carbon monoxide is the same. The mechanism, as far as we know, regarding the carburizing reaction, is through this catalyst.

We have found in looking at this data all laid out, that always the steel carrying the highest sulphur takes the quickest, deepest case. That is something that probably will please the steel makers. We were unable to account for this. We averaged it, and figured it every way we could to see why that was, and finally Dr. Wozasek used some sulphur dioxide in the gas in very minute quantities. Then we took some electrolytic iron, 99.98 per cent pure, and carburized it and got extremely abnormal results with the gas not treated with SO_2 . The cementite went in in streamers and very little pearlite was formed; there was a great excess of cementite and free ferrite. Adjacent to that piece, from the same bar, another piece was cut, and carburized with the gas, in which a very minute amount of sulphur dioxide was used, and we formed a great amount of pearlite. In fact, practically the entire matrix of the case from its ferrite inner boundary to the outer edge is all pearlitic, and the excess cementite is there in quite large amount, but with very little free ferrite, I should say 98 per cent normal, or 95 per cent normal.

G. A. UHLMAYER: You have referred repeatedly to the catalytic action produced in the retort by an iron catalyst which made the carburizing action more dependable and much quicker. May I ask in what form the iron catalyst is present?

R. G. GUTHRIE: Some form of oxide as far as we know.

G. A. UHLMAYER: Is the catalyst inserted separately in the retort?

R. G. GUTHRIE: No, the oxygen forms the catalyst with the iron.

G. A. UHLMAYER: As I understand it, the reaction taking place involving the iron oxide catalyst is actually a reaction taking place on the surface of the metal being treated. Is this correct?

R. G. GUTHRIE: Yes. It is some form of oxide below, or not as complete as Fe_2O_3 , because if we form Fe_2O_3 , we do not get those results.

G. A. UHLMAYER: Do you mind restating briefly your instructions to Mr. Frey, of the John Deere Tractor Works, as to the procedure necessary to carry on this carburizing reaction with gas so that the catalytic reaction may also take place?

R. G. GUTHRIE: I said for him to bubble his gas through water vapor in a tub or bucket or anything that will stand that pressure, and after the steel is brought up to heat, allow that saturated gas to go over the material for three or four minutes, depending upon the size of his furnace, if he has a one-ton furnace, about three minutes, then continue the run with dry gas.

ON THE CONSTITUTION AND PROPERTIES OF HARDENED STEEL

BY W. P. SYKES AND DR. ZAY JEFFRIES

Abstract

The paper describes an investigation of the changes in hardness of freshly quenched steel taking place at, above and below room temperature.

Freshly quenched high carbon steel when maintained near zero degrees Cent. does not change measurably in hardness for several hours. It hardens, however, if cooled below or heated above this temperature. The hardening on cooling is relatively independent of time but dependent upon the temperature reached. This hardening is accompanied by an increase in volume. It is clearly due to austenite transformation.

The hardening produced by heating above zero degrees Cent. is a time-temperature phenomenon. The higher the temperature the shorter the time required for a given small hardness increase, at least up to 100 degrees Cent., and presumably up to a somewhat higher temperature.

The capability of "age" hardening above zero degrees Cent. is not lost by previous hardening produced by cooling below zero degrees. In fact, the "age" hardening at room and certain higher temperatures is greater after hardening by immersion in liquid oxygen.

The maximum Rockwell "C" hardness values obtained on the carbon steels were 70.1 on a 1.23 per cent and 70.2 on a 1.58 per cent carbon steel.

A SURVEY of the literature on the nature of hardened steel and the structural changes accompanying changes in properties reveals a wide divergence of opinion. This fact was strikingly brought out in a recent paper by Sauveur.¹ Among the questions on which there are wide differences of opinion is the cause of the changes in properties at room temperature and at low temper-

¹"The Current Theories of the Hardening of Steel Thirty Years Later", A. Sauveur, *Transactions, American Institute of Mining and Metallurgical Engineers*, Vol. LXXIII, p. 859.

A paper presented before the ninth annual convention of the Society held in Detroit, September 19 to 23, 1927. Of the authors, who are members of the Society, W. P. Sykes, is metallurgical engineer, Cleveland Wire Works, Incandescent Lamp Department, General Electric Company, Cleveland, and Dr. Zay Jeffries is associated with the General Electric Co., the Aluminum Co. of America and the National Tube Co. Manuscript received August 10, 1927.

ing temperatures in recently quenched steel. These changes are so fundamental to any theory of the hardening of steel that it was thought desirable to make a further investigation of this subject. It is the purpose of the present paper to describe certain experimental results which the authors have obtained dealing principally with hardness changes and to a certain extent with changes in volume and electrical resistivity in recently quenched steel, steel quenched and cooled below room temperature and steel quenched and aged at various temperatures. The results appear to the authors to give answers to some of the most controversial phases of the hardening of steel.

HARDNESS MEASUREMENTS

The specimens used for Rockwell hardness measurements were $\frac{1}{4} \times \frac{1}{4} \times \frac{1}{2}$ -inch blocks cut from bars $\frac{1}{2}$ -inch square or larger and ground smooth on the four large faces. For quenching from temperatures up to 1652 degrees Fahr. (900 degrees Cent.) the pieces were heated in an electric muffle in which was placed a number of carbon blocks to reduce surface oxidation. For higher quenching temperatures the steels were heated in a tungsten-wound resistor furnace in a neutral atmosphere of hydrogen and methane.

In every case the steels were heated for 30 minutes at the desired temperature before quenching.

A 10 per cent solution of caustic soda was used as the quenching medium. This solution was surrounded by a bath of ice and salt by means of which the temperature of the caustic solution was held between 0 degrees Cent. and plus 3 degrees Cent.

When the hardness measurements were made directly after quenching, the specimens were ground smooth under water and tested within two minutes after removal from the quenching bath. In other cases the steels were transferred directly from the quenching bath to liquid oxygen or alcohol at -130 to -148 degrees Fahr. (-90 to -100 degrees Cent.). The subsequent hardness measurements were made within 2 minutes after removal from the cooling medium.

After each treatment of a specimen, four hardness readings were made, one on each face, two being taken near one end and two near the other. All measurements of the hard steels were made with the same diamond penetrator, which was used on no other materials during the course of the investigation. The Rockwell

machine was thoroughly cleaned and calibrated before starting the series of tests.

The aging at 122 and 158 degrees Fahr. (50 and 70 degrees Cent.) and the long time aging at 212 degrees Fahr. (100 degrees

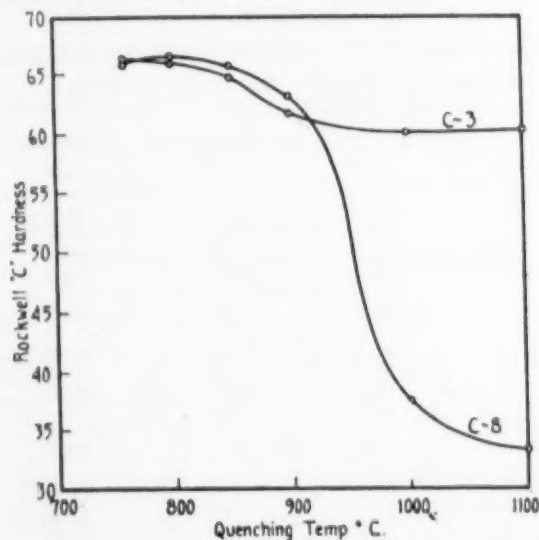


Fig. 1—Effect of Quenching Temperatures on Rockwell "C" Hardness of Two Steels. Measurements Made Within 2 Minutes After Quenching.

Cent.) was done in a constant temperature electric furnace, in which the variation was never more than 2 degrees Cent. Over the period of the tests the room temperature ranged from 72 to 86 de-

Table I
Analyses of Steels

Element	STEELS			
	C-3	C-4	C-8	C-9
C	1.23	1.00	1.87	1.58
Si	0.12	0.16	0.56	0.22
Mn	0.24	0.36	1.55	0.25
Cr	0.00	0.00	1.83	0.00
S	0.007	0.013	0.011	0.017
P	0.012	0.022	0.041	0.032
W	...	...	9.37	...

grees Fahr. (22 to 30 degrees Cent.). Some of the 212 degrees Fahr. (100 degrees Cent.) aging experiments were made by immersion in boiling water.

EFFECT OF QUENCHING TEMPERATURE ON THE HARDNESS AS QUENCHED

Four steels were used in these experiments. The marks of the

steels with analyses are given in Table I. To find the effect of quenching temperature on the hardness in the quenched condition, samples of the steels were quenched from various temperatures be-

Table II
Effect of Quenching Temperature on Rockwell "C" Hardness Measured Within 2 Minutes After Quenching

Quenching Temperature		STEEL			
Deg. C.	Deg. F.	C-3	C-4	C-8	C-9
760	1400	66.5	66.0	65.5	67.5
		66.0	66.0	66.0	68.0
		66.8	65.8	66.5	67.8
		66.2	66.0	66.2	67.5
		66.4	66.9	66.0	67.7
800	1470	66.0	66.0	66.0	67.2
		65.5	66.2	66.5	67.5
		65.5	66.0	66.5	67.2
		65.5	66.2	67.0	67.2
		65.6	66.1	66.5	67.3
850	1560	65.0	64.0	65.5	66.0
		64.5	64.2	65.8	66.2
		64.5	64.0	65.8	66.0
		65.0	64.2	65.8	66.2
		64.7	64.1	65.7	66.1
900	1652	62.0	64.5	63.5	63.5
		61.5	64.5	63.0	63.8
		62.0	65.0	63.2	63.5
		61.5	64.8	63.0	64.0
		61.7	64.7	63.2	63.7
1000	1832	61.0	63.5	37.5	54.5
		60.0	64.0	37.5	55.0
		59.0	63.8	37.0	55.0
		60.0	64.0	37.5	54.8
		60.0	63.8	37.4	54.8
1100	2012	60.0	62.5	33.0	45.2
		59.5	63.0	33.2	49.5
		61.0	62.8	34.0	50.2
		60.5	63.5	33.0	47.0
		60.2	62.9	33.3	47.9

tween 1400 and 2012 degrees Fahr. (760 and 1100 degrees Cent.) Table II shows both the individual and average hardness values.

In Fig. 1 the hardness values on steels C-3 and C-8 are plotted. It will be seen from these figures that the hardness of steel C-3 as freshly quenched decreases considerably with a rise in quenching temperature above 1562 degrees Fahr. (850 degrees Cent.). In the case of the alloy steel C-8 this decrease is much more noticeable. The highest carbon steel (C-9) is harder than the other carbon steels

after quenching from temperatures of 1562 degrees Fahr. (850 degrees Cent.) or lower, but when quenched from 1832 or 2012 degrees Fahr. (1000 or 1100 degrees Cent.) it is softer than the lower carbon steels.

TREATMENTS AT LOW TEMPERATURE

Specimens of the steels as quenched from a series of temperatures were immersed in liquid oxygen or in alcohol at -130 to

Table III
Rockwell "C" Hardness of Steels After Quenching and Cooling to Low Temperatures

Quenched from		STEEL C-3			STEEL C-4	
Deg. C.	Deg. F.	As Quenched	After Cooling to -100° C.	After Cooling to -183° C.	As Quenched	After Cooling to -183° C.
760	1400	66.4	...	66.9	66.0	66.3
800	1470	66.1	67.0	67.0	66.1	66.9
850	1560	64.7	...	66.2	64.2	65.6
900	1652	61.7	65.3	65.2	64.7	65.6
1000	1832	60.1	63.7	64.0	63.8	65.4
1100	2012	60.0	62.5	61.9	62.9	63.8

Quenched from		STEEL C-8			STEEL C-9	
Deg. C.	Deg. F.	As Quenched	After Cooling to -183° C.	As Quenched	After Cooling to 100° C.	After Cooling to -183° C.
760	1400	66.0	66.9	67.7	...	68.1
800	1470	66.5	67.9	67.3	...	67.9
850	1560	65.7	67.0	66.1	...	67.1
900	1652	63.2	66.8	63.7	65.9	65.9
1000	1832	37.3	61.0	54.8	62.9	62.7
1100	2412	33.3	35.5	48.0	60	59.2

-166 degrees Fahr. (-90 to -110 degrees Cent.) for periods of time varying between 1 minute and 30 minutes. Within 2 minutes after removal from the oxygen or alcohol each block was ground and tested for hardness on four surfaces. The resulting hardness figures are listed in Table III.

The temperature of -130 to -166 degrees Fahr. (-90 to -110 degrees Cent.) was obtained by cooling alcohol with liquid oxygen. The temperature was measured by means of a millivolt meter and thermocouple calibrated with ice, carbon dioxide snow, liquid oxygen and liquid nitrogen.

The hardening effect of this low temperature treatment is, of course, well known. It is of interest, however, to note that in these tests, at least, the treatment at -148 degrees Fahr. (-100 degrees Cent.) is fully as effective as that at -297 degrees Fahr. (-183 degrees Cent.).

ROOM TEMPERATURE AGING AFTER QUENCHING AND LIQUID OXYGEN IMMERSION

Table IV shows that freshly quenched steel hardens definitely and substantially on standing at room temperature.

Table IV
Rockwell "C" Hardness of Steels C-3 and C-4 Aged at Room Temperature After Quenching from 1560° F. (850° C.)

	As Quenched	HOURS AT ROOM TEMPERATURE					
		5	20	100	200	300	500
Steel C-3	65.0	66.2	66.5	67.0	67.0	67.2	67.2
	64.5	65.8	66.2	67.0	67.0	67.2	67.2
	65.0	66.2	66.2	66.8	67.2	67.0	67.5
	64.5	66.0	66.2	67.0	67.0	67.0	67.3
Steel C-4	64.7	66.1	66.3	66.9	67.0	67.1	67.3
	64.0	65.0	65.2	66.0	66.2	66.0	66.2
	64.2	65.2	65.5	65.8	66.0	65.8	66.2
	64.0	65.0	65.2	66.0	66.0	66.2	66.5
	64.2	65.0	65.2	65.8	66.0	66.0	66.2
	64.1	65.0	65.3	65.9	66.0	66.0	66.3

Table V shows that the hardening produced by liquid oxygen does not decrease but increases the age hardening effect at room temperature. This is a most important point, which will be dis-

Table V
Rockwell "C" Hardness of Steels C-3 and C-4, Quenched from 1560° F. (850° C.) Immersed in Liquid Oxygen and Aged at Room Temperature (22° C. to 30° C.)

	As Quenched	After 5 Min. in			HOURS AT ROOM TEMPERATURE					
		Liq. O ₂	5		20	100	200	500	800	1600
Steel C-3	65.0	66.2	67.2	67.5	68.5	68.8	69.0	70	70	
	65.0	66.5	67.0	67.5	68.2	68.5	69.2	69.5	70	
	64.5	66.2	67.0	67.8	68.2	69	69.0	69.8	70	
	65.0	66.0	67.2	67.8	68.5	68.8	69.2	69.8	70	
	64.9	66.2	67.1	67.6	68.3	68.7	69.1	69.8	70	
Steel C-4	64.5	65.5	66.2	67.0	67.5	68.0	68.0	69.0	..	
	64.2	65.8	66.5	66.8	67.5	68.0	68.2	68.8	..	
	64.0	65.5	66.0	67.0	67.8	68.2	68.0	69.0	..	
	64.0	65.5	66.5	66.8	67.5	67.8	68.2	69.0	..	
	64.2	65.6	66.3	66.9	67.6	68.0	68.1	68.9	..	
	64.2	65.6	66.3	66.9	67.6	68.0	68.1	68.9	..	

cussed later. Table VI brings out the further important and fundamental fact, that the low temperature treatment produces a change which is as great in 1 minute as in 30 minutes, whereas the degree of hardening by room temperature aging is a function of time.

Table VI

Rockwell "C" Hardness of Steel C-3 Quenched from 1470° F. (800° C.) and Treated as Shown

Time at -183° C.	TIME AT ROOM TEMPERATURE AFTER REMOVAL FROM LIQUID OXYGEN							
	2 Min.	15 Min.	30 Min.	1 Hr.	5 Hrs.	200 Hrs.	400 Hrs.	800 Hrs.
1 Min.	67.0	67.8	67.8	68.0	68.2	69.0	69.2	69.5
	67.0	67.5	67.5	68.0	68.0	69.2	69.5	69.8
	66.8	67.5	67.8	68.2	68.2	68.8	69.5	69.5
	67.2	67.8	68.0	67.8	68.0	69.0	69.5	69.8
	67.0	67.6	67.7	68.0	68.1	69.0	69.4	69.6
5 Min.	67.0	67.8	68.0	68.0	68.0	69.2	69.5	69.8
	66.8	67.5	67.8	68.0	68.0	69.2	69.5	69.8
	67.5	68.8	68.0	68.2	68.0	69.0	69.5	69.5
	66.8	67.5	67.8	68.0	68.0	69.2	69.5	69.8
	67.0	67.6	67.9	68.0	68.0	69.1	69.5	69.7
30 Min.	66.5	67.2	67.8	68.0	68.0	69.2	69.5	69.8
	67.2	67.8	67.8	68.0	68.0	69.5	69.8	69.5
	67.0	67.5	68.0	67.8	68.2	69.5	69.8	69.8
	67.2	67.5	68.0	68.2	68.2	69.2	69.8	69.8
	66.9	67.5	67.9	68.0	68.1	69.3	69.7	69.7

AGING ABOVE ROOM TEMPERATURE

Table VII shows that aging at 212 degrees Fahr. (100 degrees Cent.) increases the hardness of steel C-3 after quenching, that a hardness maximum is reached after about 5 hours, after which the hardness decreases on more prolonged aging. The steel quenched and immersed in liquid oxygen goes through the same general cycle of hardness changes, but the maximum hardness obtained is greater than in the samples not immersed in liquid oxygen. Aging at 167 degrees Fahr. (75 degrees Cent.) shows hardness increase in the same direction as aging at 212 degrees Fahr. (100 degrees

Table VII

Rockwell "C" Hardness of Steel C-3 Quenched from 1560° F. (850° C.) and Treated as Shown

As Quenched	After Immersion in Liquid Oxygen	TIME OF AGING AT 75 DEG. CENT. (HOURS)								
		1	5	15	20	25	30	40	65	90
64.7	Not immersed	66.8	67.1	67.4	67.7	67.8	67.8	67.8	67.5	67.3
64.8	66.1	68.8	69.1	69.4	69.7	69.7	69.7	69.7	69.5	69.3
		TIME OF AGING AT 100 DEG. CENT.								
		5 Min.	1 Hr.	2 Hrs.	5 Hrs.	20 Hrs.	50 Hrs.	65 Hrs.	90 Hrs.	100 Hrs.
64.6	Not immersed	...	66.8	67.1	68.0	66.9	...	66.9	...	66.9
64.7	66.0	68.0	69.0	...	69.0	68.1	67.7	...	...	67.7

Table VIII

Steel	As Quenched	After 5 Min. in Liquid Oxygen	30 Min.	1 Hr.	TIME OF AGING AT 50 DEGREES CENTIGRADE												215 Hrs.	260 Hrs.	300 Hrs.
					5 Hrs.	20 Hrs.	50 Hrs.	75 Hrs.	100 Hrs.	125 Hrs.	150 Hrs.	185 Hrs.							
C-3	64.7	66.2	68.0 67.8 67.5 67.8	68.0 68.0 67.8 68.0	69.0 68.8 68.8 68.8	69.0 69.2 69.0 69.2	69.5 69.2 69.5 69.5	69.8 69.5 69.8 69.8	69.8 69.8 70.0 70.0	70.0 70.2 70.0 70.2	70.0 70.2 70.0 70.2	70.0 70.2 70.0 70.2	69.8 70.0 69.5 69.8	69.8 70.0 69.5 69.8	69.8 70.0 69.5 69.8				
C-9	66.1	67.1	67.5 67.2 67.5 67.8	68.0 67.8 68.2 68.0	68.5 68.8 69.0 68.5	69.1 69.2 69.5 69.0	69.4 69.8 69.8 69.8	69.7 69.8 70.0 69.8	69.9 70.0 70.2 70.2	70.1 70.2 70.2 70.2	70.1 70.2 70.2 70.2	70.1 70.2 70.2 70.2	70.1 70.0 70.2 70.0	70.1 70.0 70.0 70.0	70.0 70.0 70.0 70.0				

Cent.). From 20 to 40 hours aging is required at 167 degrees Fahr. (75 degrees Cent.) to produce maximum hardness. The maximum hardness value (69.7) obtained by aging at 167 degrees Fahr. (75 degrees Cent.) was higher than that (69) obtained by aging at 212 degrees Fahr. (100 degrees Cent.). This suggests that at some temperature lower than 167 degrees Fahr. (75 degrees Cent.) a still greater hardening effect might be found.

The results given in Table VIII show that steels C-3 and C-9 quenched and immersed in liquid oxygen and then aged 150 hours at 122 degrees Fahr. (50 degrees Cent.) have Rockwell "C" hardness values above 70. This treatment produces the highest hardness of any thermal treatment known to the authors.

Table IX shows that at a temperature of 0 to +3 degrees Cent. "age" hardening is not measurable after 5 hours, and is only as great after 50 hours as after 30 minutes at room temperature. Some

Table IX
Rockwell "C" Hardness of Steel C-3 Treated as Shown

Time at 0° C. to + 3° C. After Quench	SUBSEQUENT TIME AT ROOM TEMPERATURE						
	2 Min.	15 Min.	30 Min.	1 Hr.	50 Hrs.	200 Hrs.	700 Hrs.
1 Hr.	66.1	66.8	67.0	67.2	68.0	68.4	68.8
5 Hrs.	66.0	66.7	67.0	67.2	67.8	68.2	68.8
50 Hrs.	66.9	67.2	67.1	67.2	67.9	68.3	68.8

NOTE: Each hardness figure is an average of four readings.

of the "age" hardening effects are charted in Figs. 2 and 3. Fig. 4 shows the time-temperature relations for producing maximum hardness in 1.23 per cent carbon steel. It is not known whether softening will follow attainment of maximum hardness on aging at room temperature.

Special attention was given to the method of hardening alternately in liquid oxygen and boiling water. The results strongly indicate that the hardening brought about by this treatment is no greater than the sum of the increases in hardness due to the low temperature and the 212 degrees Fahr. (100 degrees Cent.) heating employed separately. That is to say, immersion of the steel in liquid oxygen for 5 minutes, then in boiling water for five minutes, will result in the same hardness increase as would be obtained from five cycles of one minute immersions alternately in

liquid oxygen and boiling water. The following experiments illustrate this point. Six specimens of steel C-3 were quenched

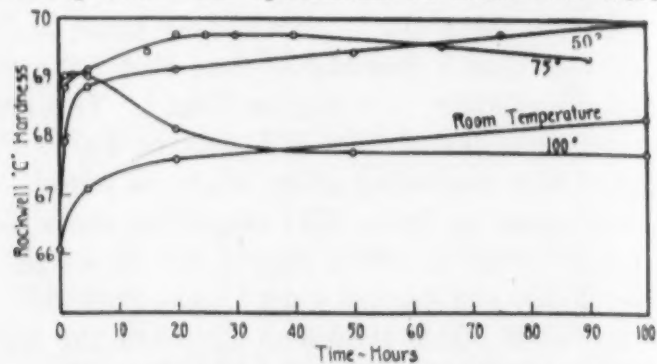


Fig. 2—Relation Between Rockwell "C" Hardness and Aging Time and Aging Temperature of 1.23 Per Cent Carbon Steel Quenched from 1562 Degrees Fahr. (850 Degrees Cent.) and Quenched in Liquid Oxygen.

from 850 degrees Cent. One had a hardness of 64.8 as quenched, 66.1 after 5 minutes in liquid oxygen, and 68 after the liquid oxygen treatment plus 5 minutes in boiling water. Another specimen had

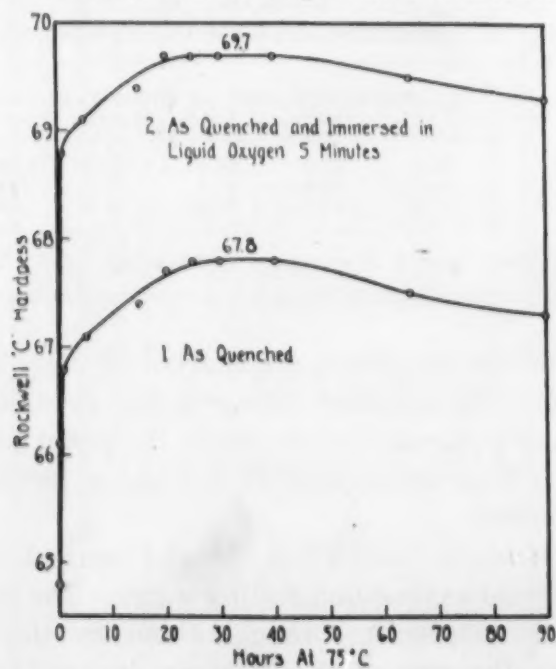


Fig. 3—1.23 Per Cent Carbon Steel Aged at 165 Degrees Fahr. (75 Degrees Cent.) Before and After Immersion in Liquid Oxygen.

a hardness of 64.7 as quenched, 66 after one minute in liquid oxygen, and 67.6 after an additional one minute in boiling water. After three of these one-minute cycles, the hardness was 67.9, and

after five cycles the hardness was 68. Another specimen had a hardness of 64.7 as quenched, 66 after five minutes in liquid oxygen, and 67.6 when the liquid oxygen treatment was followed by 5 minutes in water at 70 degrees Cent. A companion specimen had a hardness of 64.9 as quenched, and 67.5 after 5 cycles, each cycle consisting of one minute in liquid oxygen and one minute in water

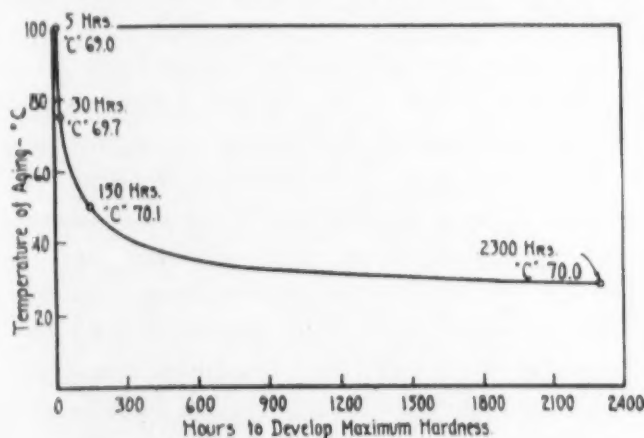


Fig. 4—Relation Between Aging Temperature and Aging Time to Produce Maximum Hardness in Quenched High Carbon Steel.

at 70 degrees Cent. In the third series the first specimen had a hardness of 64.9 as quenched and 66.2 after 5 minutes in liquid oxygen. When this treatment was followed by 5 minutes in water at 25 degrees Cent. the hardness was 66.4. The companion specimen had a hardness of 64.7 as quenched, and after 5 cycles consisting of one minute in liquid oxygen followed by one minute in water at 77 degrees Fahr. (25 degrees Cent.) the hardness was 66.3. These experiments illustrate nicely the fundamental fact that *time* is not an important factor in the liquid oxygen hardening, but it is an *important factor* in the hardening at room temperature and slightly above.

EXPERIMENTS ON IRON, LOW CARBON STEEL AND IRON-NICKEL ALLOY

Iron produced by hydrogen reduction was briquetted and sintered at a temperature below the melting point and then mechanically worked. By chemical analysis no element other than iron could be positively identified. Hereinafter this material will be referred to as pure iron. Pieces $\frac{1}{8} \times \frac{1}{4} \times 1$ -inch were prepared for hardness measurements.

After heating to 1832 degrees Fahr. (1000 degrees Cent.) for 30 minutes and cooling in air the average of eight readings on the Rockwell "B" scale was 41.8. When quenched in iced caustic soda solution from 1832 degrees Fahr. (1000 degrees Cent.) the average Rockwell "B" hardness was 53.4. The average of 48 hardness readings on six specimens as quenched from 1742 to 2192 degrees Fahr. (950 to 1200 degrees Cent.) was 54.2. The average of 54 readings on the same specimens after aging from 30 minutes to 2 hours at 212 degrees Fahr. (100 degrees Cent.) was 54.9. There appears to be no substantial hardening on aging at 212 degrees Fahr. (100 degrees Cent.). Immersion in liquid oxygen after quenching produced no measureable change in hardness.

Specimens of Arceo iron $\frac{1}{4} \times \frac{1}{4} \times \frac{1}{2}$ -inch and $\frac{1}{8} \times \frac{1}{4} \times 1$ -inch were prepared for heat treatment and hardness experiments. After heating to 1832 degrees Fahr. (1000 degrees Cent.) for 30 minutes and air cooling, the Rockwell "B" hardness was 46.5. The hardness did not change either by liquid oxygen immersion or on aging at 212 degrees Fahr. (100 degrees Cent.). After quenching Arceo iron from 1742 to 2192 degrees Fahr. (950 to 1200 degrees Cent.) the hardness was substantially increased as compared with the air cooled samples. The average of 80 Rockwell "B" hardness readings immediately after quenching was 73.2. There was no appreciable change in hardness after immersion in liquid oxygen. On heating to 212 degrees Fahr. (100 degrees Cent.), however, after quenching, the hardness was slightly but definitely increased. The average of 56 readings on 7 specimens heated 30 minutes to 2 hours at 212 degrees Fahr. (100 degrees Cent.) after quenching was 79.2. The hardness increase was also easily measureable after 24 hours room temperature aging, after quenching. The average of 40 readings was 73.1 within two minutes after quenching. After 24 hours at room temperature the average of 40 Rockwell "B" hardness readings was 78.9. The hardness increase is about as much in 24 hours at room temperature as in 30 minutes, one hour, or two hours at 212 degrees Fahr. (100 degrees Cent.).

Some tests were made on $\frac{1}{4} \times \frac{1}{4} \times \frac{1}{2}$ -inch blocks of low carbon steel containing 0.11 per cent carbon, 0.62 per cent manganese and 0.25 per cent silicon. The average of 20 Rockwell "B" hardness readings within two minutes after quenching from 1832 degrees Fahr. (1000 degrees Cent.) was 110.5. Aging 30 minutes at 212

1927

degrees Fahr. (100 degrees Cent.) after quenching gave 110.8 as an average of 16 hardness readings on four specimens. After aging one hour at 212 degrees Fahr. (100 degrees Cent.) the average of 16 hardness readings on four specimens was 111.6, and after two hours aging at 212 degrees Fahr. (100 degrees Cent.) the average hardness was 111.6. On aging the as quenched samples 100 hours at room temperature, there was no measureable change in hardness.

The hardness measurements on iron and low carbon steel were not nearly as uniform and consistent as on the high carbon steels. The uniformity, however, was greater on the pure iron and low carbon steel than on the Armco iron. The variation in hardness in the as quenched Armco iron was from 55 to 83, and in the samples aged at 212 degrees Fahr. (100 degrees Cent.) the variation was from 65 to 85. All of the readings on the low carbon steel were between 104 and 115. The spread on the pure iron was from 50 to 58. Tests on an iron-nickel alloy containing 19 per cent nickel, prepared in Dr. Honda's laboratory, showed a hardness immediately after quenching from above the critical range of 18 in the Rockwell "C" scale. The hardness was not changed by aging 5 hours at 100 degrees Cent.

DISCUSSION OF HARDNESS RESULTS

It is apparent from the results on the high carbon steels that the conditions of test permit the determination of the changes in direction of hardness as well as variation in actual hardness values within limits not ordinarily considered feasible with any hardness tester. This was possible as the result of unusual care, not only in making the hardness measurements but also in the preparation of the test specimens. The large number of individual measurements, several duplications not recorded in the above data, and the consistency of the hardness values on the same and different steels all add to the certainty of the substantial correctness of the values given.

The interpretation of the hardness measurements after the various treatments will be considered with respect to certain of the current ideas.

The variations in hardness with change in quenching temperature as shown in Fig. 1 and Table II are in accord with many previous observations. The lower hardness values obtained at the

higher quenching temperatures are supposed to be due to the retention of more austenite. Not only has this interpretation been confirmed by X-ray analysis by Bain, Lester, Harder and Dowdell, and others, but it is also confirmed in the present investigation by the increase in hardness after immersion in liquid oxygen. There is universal agreement that liquid air or oxygen immersion of a quenched steel may convert austenite to martensite, and so far as is known will produce no other structural change.

Table III shows that the hardness of a 1.23 per cent carbon steel quenched from 1400 degrees Fahr. (760 degrees Cent.) is increased only slightly (from 66.4 to 66.9) by cooling to -148 or -297 degrees Fahr. (-100 or -183 degrees Cent.). The inference is that only a small amount of softer austenite has been converted into the harder martensite at the low temperature. On the other hand, the same steel quenched from 1652 degrees Fahr. (900 degrees Cent.) shows a more substantial increase in hardness after cooling to a low temperature. This is evidence of conversion of more austenite to martensite. The final hardness after quenching and cooling to a low temperature is less the higher the quenching temperature above about 1472 degrees Fahr. (800 degrees Cent.) which would indicate less complete conversion of the austenite the higher the quenching temperature or the production of a softer martensite. This subject has been investigated recently by Harder and Dowdell.²

Increase in hardness by low temperature treatment of a quenched steel is to be regarded as proof of the conversion of austenite to martensite and hence proof of the retention of austenite by quenching. Failure to effect an increase in hardness in quenched steel by low temperature treatment is to be regarded as evidence of no conversion of austenite, but is not to be regarded as evidence of the absence of austenite in the quenched steel. This holds particularly for the higher quenching temperatures which favor the retention of austenite. Austenite retained from a high temperature quench seems to be relatively resistant to conversion to martensite by low temperature treatments. This is probably the result of two factors, (1) the higher quenching temperatures produce an austenite richer in elements other than iron, and (2), the stability of the austenite apparently increases with increase in grain size. In

²Harder and Dowdell, "The Decomposition of the Austenitic Structure in Steels", TRANSACTIONS, American Society for Steel Treating. Seven articles, January to July, inclusive, 1927.

Table III, for example, steel C-3 quenched from 1832 and 2012 degrees Fahr. (1000 and 1100 degrees Cent.) shows about the same hardness and supposedly about the same amount of retained austenite. In cooling below room temperature, the 1832 degrees Fahr. (1000 degrees Cent.) quench shows a greater increase in hardness. The austenite should be saturated in carbon at either quenching temperature, but the grain size of the 2012 degrees Fahr. (1100 degrees Cent.) quench should be the larger.

Past investigations may have confused the increased hardness due to the conversion of austenite to martensite at temperatures below room temperature. The alternate immersions in liquid air and boiling water, for example, appear to convert more austenite than one immersion in liquid air. When hardness increase is used as a measure of the amount of austenite converted this method gives high results as shown above. In the low temperature treatments the time of holding at temperature is of little importance. Furthermore, a temperature of -148 degrees Fahr. (-100 degrees Cent.) seems to give about the same results as -297 degrees Fahr. (-183 degrees Cent.), or even -423 degrees Fahr. (-253 degrees Cent.) (liquid hydrogen). The time of holding at room temperature or above, however, is most important as can be seen from the curves and tables. Here is the first real differentiation between the change which occurs at and near room temperature, and that which occurs on cooling below room temperature; the former is a *time-temperature* phenomenon, and the latter is a *temperature* phenomenon.

Now the discussion enters into more controversial territory. Although there is universal agreement that the change produced when a quenched steel is immersed in liquid air represents a transformation from austenite to martensite, there is much difference of opinion as to what the nature and constitution of martensite are. There is much difference of opinion with respect to the changes at and near room temperature. Some hold that the increase in hardness accompanying these changes must be due to the further transformation of austenite to martensite.³

Others believe that the hardening which takes place in recently quenched steels at and near room temperature is due to the precip-

³Honda and Idei, "Science Reports", Tohoku Imperial University, Vol. 9, No. 6, 1920; Honda, TRANSACTIONS, American Society for Steel Treating, March, 1927, p. 412.

itation of the carbide.⁴ This idea is necessarily based on the assumption that the carbide is not precipitated in freshly formed martensite. There are also those who believe that the carbide always forms simultaneously with the alpha iron on the transformation of austenite, and that freshly formed martensite is fully hard.⁵

The results obtained on Armco iron indicate that hardening can take place at room temperature and slightly above after quenching with only 0.02 per cent carbon present. This hardening cannot logically be associated with the conversion of austenite. The liquid oxygen treatments indicate no conversion of gamma to alpha iron, and in an experiment to be described later it is shown that the hardness change is not accompanied by a sufficient change of volume to detect on a 6-inch gage length with a sensitive micrometer.

The absence of a decrease in volume during age hardening, the relatively rapid rate of hardening at room temperature after quenching as compared with the rate at 212 degrees Fahr. (100 degrees Cent.), and the greater magnitude of the age-hardening of Armco iron containing 0.02 per cent carbon as compared with the steel containing 0.11 per cent carbon, are arguments against carbide precipitation as a cause of this age hardening.

The results on Armco iron are consistent with the introduction of slight strain hardening by quenching. The hardening would be attributed to the "healing" of slip planes after recent straining, as suggested by Archer.⁶ As a rough estimate of the degree of strain hardening required to produce the "age" hardening effect found in the Armco iron, a piece was annealed after which its Rockwell "B" hardness was 51. The specimen was then compressed somewhat above its yield point immediately after which its hardness was 74.5. After aging 30 minutes at 100 degrees Cent. its hardness had increased to 82. This sample showed more "age" hardening in 30 minutes at 100 degrees Cent. than the quenched samples did in one hour at the same temperature. It seems, therefore, that sufficient permanent deformation in the ferrite of Armco

⁴Jeffries and Archer, *TRANSACTIONS, American Society for Steel Treating*, Vol. 4, 1923, p. 294.

⁵Scott, *TRANSACTIONS, American Society for Steel Treating*, Vol. 9, 1926, p. 275.

⁶Bain, *Transactions, American Institute of Mining and Metallurgical Engineers*, Vol. LXXIII, 1920, p. 884.

⁷Rosenhain, *Journal, Iron and Steel Institute*, Vol. 110, No. 2, 1924, p. 145.

⁸R. S. Archer, *Transactions, American Institute of Mining and Metallurgical Engineers*, Vol. LXVII, 1922, p. 73.

iron could take place due to the rapid cooling and volume changes incident to the transformation of gamma to alpha iron to account for the "age" hardening effect noted.

The lesser "age" hardening effect in pure iron might be attributed to a higher temperature of transformation during quenching, thus lessening the degree of "cold work," or it might be supposed that pure iron does not exhibit the property of "age" hardening after over strain. To answer the latter point a piece of pure iron was compressed at room temperature slightly beyond the yield point after which its Rockwell "B" hardness was 69. After aging 30 minutes at 212 degrees Fahr. (100 degrees Cent.) the hardness had increased to 76, showing that pure iron exhibits the overstrain effect.

A piece of the annealed 0.11 per cent carbon steel was compressed cold slightly beyond its yield point after which its Rockwell "B" hardness was 70. After aging 30 minutes at 212 degrees Fahr. (100 degrees Cent.) the hardness had increased to 76. This is a considerably greater increase than is found after quenching.

It is apparent that all of the "age" hardening results on quenched pure iron, Armco iron, and 0.11 per cent carbon steel are consistent in magnitude, direction and time-temperature relations with the production of a slight amount of permanent deformation during quenching. Also the greatest effect noted in Armco iron is only on the order of one-fifth the magnitude of the hardness increases found in high carbon steel. These considerations coupled with the marked decrease in volume accompanying the "age" hardening of high carbon steels lead us to the conclusion that some factor other than overstrain in the high carbon steels is chiefly responsible for the changes in properties.

The results obtained in the present researches are in accord with the existing great mass of data to the effect that the first transformation of austenite to martensite represents a change from gamma to alpha iron without substantial precipitation of the carbide. Among the reasons for assuming that the carbide has not precipitated are:

1. The suddenness of the transformation when certain temperatures are reached during cooling, indicating that time for carbon diffusion is not necessary.
2. The expansion accompanying the formation of marten-

site is commensurate with the expansion accompanying the change from gamma to alpha iron.

Austenite is known to transform to martensite at temperatures considerably below 32 degrees Fahr. (0 degrees Cent.) Such a transformation should not be accompanied by carbide precipitation because the transformation takes place within one minute and time would not be permitted for the carbide to precipitate even if the carbon could diffuse slowly at these low temperatures. Now the formation of martensite at very low temperatures seems to be accompanied by the same general changes as its formation at and above room temperature. Furthermore the martensite produced within either temperature range behaves similarly toward subsequent treatments. The evidence favors the retention of the carbon in solution in martensite at the time of its formation, whether it be above or below room temperature.

On the basis of this conclusion the results of the room temperature and slightly elevated temperature aging are simply interpreted. Freshly formed martensite is supersaturated in carbon which will precipitate when temperature and time conditions permit. Such precipitation involves diffusion of the carbon and requires that the temperature be above a certain minimum and that the *time* for a given state of precipitation be greater the lower the temperature. The major factor in the increase in hardness found on aging appears to be the precipitation of the carbide. The laws of precipitation hardening have now been worked out on several systems^{7, 8} to such an extent that compliance with certain requirements may be used as evidence of precipitation hardening. The aging of freshly quenched high carbon steel complies with these requirements.

1. A certain low temperature is found below which aging does not take place. This is slightly below 32 degrees Fahr. (0 degrees Cent.) in steel C-3.

2. As the temperature is raised above this low temperature, aging proceeds slowly, the rate increasing as the temperature is increased.

3. Aging above a certain temperature results in an increase

⁷Merica, Waltenberg and Scott, *Transactions*, American Institute of Mining and Metallurgical Engineers, Vol. 64, p. 41.

⁸R. S. Archer, *TRANSACTIONS*, American Society for Steel Treating, Vol. 10, September, 1926.

of hardness, the hardness value reaching a maximum after a certain time after which the hardness decreases.

4. At any aging temperature at which the hardness time curve passes through a maximum hardness value, the actual hardness at the maximum of the curve is greater the lower the aging temperature. Also a longer time is required to attain the maximum of the curve the lower the aging temperature.

It may be argued that age hardening after overstrain complies with all of the above requirements. There are two changes during aging of quenched high carbon steel which have not been associated with hardening after overstrain, namely, marked heat evolution and marked decrease in volume. These changes clearly indicate carbide formation.

The question may properly be asked what the evidence is that the age hardening is not caused by further and gradual decomposition of the austenite. In the first place the above results show less age hardening in the steels retaining most austenite on quenching. Conversely the steels showing most martensite show the greatest age hardening effect. This is evidence that the major change causing the increase in hardness is not in the austenite, but in the martensite. This conclusion is fully confirmed by the aging results of quenched steels before and after immersion in liquid oxygen. According to the view that the age hardening is due to the transformation of austenite to martensite the age hardening effect should be materially reduced or even eliminated by liquid oxygen immersion. By comparing Table IV with Table V it will be noted that not only is the hardness of the liquid oxygen treated steels greater than that of the same steels not so treated after aging 500 hours at room temperature, but also the numerical increase in hardness produced by aging is greater in the liquid oxygen treated steels. Fig. 3 shows the aging effects at 167 degrees Fahr. (75 degrees Cent.) before and after liquid oxygen immersion. These facts are evidence that the age hardening is due to a change in the martensite rather than in the austenite. Importance is attached to the greater numerical increase in hardness of the liquid oxygen treated steel because this is positive evidence of a greater hardening effect. It would be expected that a hardness increase of one unit from say 68 to 69 would represent a greater actual increase in hardness than from say 66 to 67. It is also probable that a

given amount of precipitation will produce less numerical increase in hardness the greater the hardness prior to such precipitation.

Again if a quenched steel is aged for 500 hours at room temperature and is then immersed in liquid oxygen there is a substantial and *sudden* increase in hardness typical of the austenite transformation. The austenite retained by quenching has therefore not disappeared during aging.

The final and most positive differentiation between hardening by austenite transformation and by precipitation is the different directions of volume change. When austenite changes to martensite the volume increases, and when carbide precipitates the volume decreases. These are the known directions of volume change at higher temperatures and there is no reason to suspect any change of direction at low temperature. The formation of martensite whether above or below room temperature is accompanied by expansion. The aging of quenched steel is accompanied by a contraction in volume. Both changes produce hardening, and both evolve heat. The volume changes and the *rates* of the changes become the principal means of differentiation. According to Brush⁹ and Scott¹⁰ the dominating dimensional change on aging is a volume contraction. All of the aging changes, therefore, are consistent with carbide precipitation and not with austenite transformation.

Even supposing that the increase in hardness at say 212 degrees Fahr. (100 degrees Cent.) can be attributed to austenite transformation, how is the decrease in hardness after the maximum has been reached to be explained? Changes in the martensite are resorted to explain the softening. The same is true of the 167 and 122 degrees Fahr. (75 and the 50 degree Cent.) changes. If change in the martensite must be resorted to at these low temperatures why not attribute increase in hardness also to the changes in the martensite? These changes are just what should accompany carbide precipitation.

Certain of the changes occurring during the tempering of quenched carbon steel between 392 and 572 degrees Fahr. (200 and 300 degrees Cent.) and at higher temperatures in some of the alloy steels are clearly due to a transformation of retained austen-

⁹Brush, Bulletin No. 153, American Institute of Mining and Metallurgical Engineers, p. 2389.

¹⁰Scott, TRANSACTIONS, American Society for Steel Treating, Vol. 9, 1926, p. 275.

ite.¹¹ These changes occur after the aging treatments described in the present investigation giving further evidence that the retained austenite has not been "used up" in producing the observed increases in hardness. The greater increase in hardness at 212 degrees Fahr. (100 degrees Cent.) in the specimens of steel C-3, quenched but not immersed in liquid oxygen, as compared with specimens with the same treatment aged at room temperature suggests that at 212 degrees Fahr. (100 degrees Cent.) some of the increase in hardness may be due to austenite conversion. The results point to this in any case, however, as being a *minor* factor.

The authors would like to call especial attention to the very high hardness values obtained. No heat treatment of a plain carbon steel was known to them which would produce a Rockwell "C" hardness of 70 or above. The procedure followed in order to obtain these high hardness values follows very directly from the general hardening theory. First it is desirable to obtain an austenite as rich in carbon as can be transformed largely to martensite. Next it is necessary to age or temper the martensite so as to produce critical dispersion of the carbide. The transformation of austenite at temperatures below room temperature permits the production of a steel consisting mostly of martensite relatively rich in carbon. When this martensite is "age" hardened high hardness values are obtained. Attempts were made to convert by thermal treatment alone austenite still richer in carbon and other alloying elements into martensite, with the hope of obtaining even higher hardness values after age-hardening. This was the purpose of the liquid hydrogen immersions which were kindly carried out by the U. S. Bureau of Standards. The results are given in Table X. It is evident that liquid hydrogen is only about as effective as liquid oxygen and alcohol at -148 degrees Fahr. (-100 degrees Cent.) in converting austenite in samples $\frac{1}{4}$ inch square and $\frac{1}{2}$ inch long. The lower temperature treatments might be more effective on larger samples.

Conversion of the carbon-rich austenite by mechanical de-

¹¹Harder and Dowdell, TRANSACTIONS, American Society for Steel Treating, Vol. 12, 1927, p. 51.

Scott, TRANSACTIONS, American Society for Steel Treating, Vol. 9, 1926, p. 275.

Mathews, TRANSACTIONS, American Society for Steel Treating, Vol. 8, 1925, p. 565.

Bain and Grossmann, TRANSACTIONS, American Society for Steel Treating, Vol. 5, 1924, p. 89, and Vol. 9, 1926, p. 259.

Enlund, *Journal*, Iron and Steel Institute, No. 1, 1925, p. 305.

formation followed by "age" hardening was also considered as a means of producing great hardness but time has not yet permitted the carrying out of these experiments.

Because the change in volume accompanying increase in hardness is so important in the interpretation of the cause of the hard-

Table X
Rockwell "C" Hardness of Steels C-3 and C-8 One Series Immersed in Liquid Oxygen -297° F. (-183° C.) and One in Liquid Hydrogen -423° F. (-253° C.) After Quench

Quenched from	Immersed 45 Min. in Liquid Oxygen and Aged 800 Hrs. at Room Temp.		Immersed 45 Min. in Liquid Hydrogen and Aged 800 Hrs. at Room Temp.	
	Steel C-3	Steel C-8	Steel C-3	Steel C-8
800° C.	68.6	69.0	68.9	68.9
900° C.	67.7	68.7	66.9	67.2
1000° C.	66.7	63.2	67.0	64.0
1100° C.	66.2	36.0	66.2	37.0

NOTE: Steel C-3 Aged at Room Temperature 100 Hours After Quench Before Liquid Hydrogen Treatment. The Series Immersed in Liquid Oxygen Aged 75 Hours at Room Temperature Before Cooling to -183° Cent.

ening it was thought desirable to correlate the volume changes and hardness changes on the same piece of steel. The discovery that a quenched steel can be maintained at 32 degrees Fahr. (0 degrees Cent.) for a considerable time without change in hardness suggested also the possibility of measuring changes in electrical resistivity accompanying the volume and hardness changes.

Special Experiments

A rod of steel C-8, 6 inches long and $\frac{1}{4}$ inch square was heated in a neutral atmosphere of hydrogen and natural gas for 30 minutes at 1832 degrees Fahr. (1000 degrees Cent.) and quenched in iced caustic soda solution. While at a temperature of about 32 degrees Fahr. (0 degrees Cent.) the Rockwell "C" hardness was determined and found to be 44. The length was originally 6.000 inches at room temperature. After quenching the length was found to be 5.9885 inches at 33.8 degrees Fahr. (1 degree Cent.)

The electrical resistivity was then measured by comparison with Armco iron. The method was briefly to connect the standard piece of Armco iron in series with the test specimen using a current of about 25 to 26 amperes. The samples were immersed in a

bath of kerosene. A potentiometer was connected with a rider containing needle point contacts 4 inches apart on both the standard and test specimens. The millivoltage was determined by taking a number of readings alternately on the standard and test specimens.

The specific resistivity of the Armco iron at 35.6 degrees Fahr. (2 degrees Cent.) was 9.5 microhms per cubic centimeter. In the condition as quenched the resistivity of steel C-8 was 7.144 times that of Armco iron.

The steel was then immersed in liquid oxygen for 5 minutes after which its Rockwell "C" hardness had increased from 44 to 61. The length had increased from 5.9885 to 6.0225 at 1 degree Cent. The electrical resistance had increased on a 4-inch gage length from 7.144 to 7.206. By allowing for the expansion of the specimen and hence increase in cross section, the specific resistivity of the bar after immersion in liquid oxygen appears to have been increased by something more than 1 per cent.

The same bar of steel was then reheated for 30 minutes to 1832 degrees Fahr. (1000 degrees Cent.) in a neutral atmosphere, and quenched in iced caustic soda solution. The hardness was then 45.25. The length was 5.9945 inches and diameter was .2551 inches at 1 degree Cent. The resistance was 7.197 times that of Armco iron at 35.6 degrees Fahr. (2 degrees Cent.)

The specimen was then immersed 5 minutes in liquid oxygen after which the hardness had increased from 45.25 to 63.5. The length increased from 5.9945 to 6.025 at 33.8 degrees Fahr. (1 degrees Cent.) The diameter increased from .2551 to .2567 at 33.8 degrees Fahr. (1 degree Cent.) The electrical resistivity increased from 7.197 to 7.216 times that of Armco iron. The latter figure should be increased by about 1 per cent to compensate for increased cross section if it is desired to compare specific resistivities.

The bar of steel was then heated 30 minutes at 212 degrees Fahr. (100 degrees Cent.) By this treatment the Rockwell "C" hardness was increased from 63.5 to 66. The length was decreased from 6.025 inches to 6.0215 at 1 degree Cent. The electrical resistivity was reduced from 7.216 to 6.932 times that of Armco iron at 35.6 degrees Fahr. (2 degrees Cent.)

Another sample of steel C-8, $\frac{1}{4}$ inch square and 6 inches long

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was quenched from 1877 degrees Fahr. (1025 degrees Cent.) The hardness was 39.7, the length 5.9820 inches and electrical resistivity 7.668 times that of Armco iron at 35.6 degrees Fahr. (2 degrees Cent.) After immersing in liquid oxygen 5 minutes, the hardness had increased to 54.5, the length to 6.0100 in., and the electrical resistivity to 7.720 times that of Armco iron at 35.6 degrees Fahr. (2 degrees Cent.) After 30 minutes treatment in boiling water the hardness had increased to 56.2, the length had decreased to 6.0075 in., and the electrical resistivity had decreased to 7.578 times that of Armco iron at 35.6 degrees Fahr., (2 degrees Cent.)

A bar of steel C-3, 6 inches long and $\frac{1}{4}$ inch square was heated 30 minutes at 1832 degrees Fahr. (1000 degrees Cent.) and quenched in iced caustic soda solution. The hardness was 58.2. The length at 33.8 degrees Fahr. (1 degree Cent.) was 6.0170 inch and diameter was 0.2521 inch. The electrical resistivity was 4.929 times that of Armco iron at 33.8 degrees Fahr. (1 degree Cent.)

The steel after these measurements was immersed 5 minutes in liquid oxygen. The hardness had increased from 58.2 to 63.6. The length had increased from 6.0170 at 33.8 degrees Fahr. (1 degree Cent.) to 6.0320 inches. The diameter had increased from 0.2521 to 0.2526 inches. The electrical resistivity had decreased from 4.929 to 4.791 times that of Armco iron at 33.8 degrees Fahr. (1 degree Cent.) Even after full allowance for increased cross section by the liquid oxygen treatment the resistivity has been definitely lowered due to the low temperature transformation.

This steel was then aged at room temperature for 40 hours after which its hardness had increased from 63.6 to 65.8, and its length had decreased from 6.0320 to 6.0290 inches at 35.6 degrees Fahr. (2 degrees Cent.) Its electrical resistivity was reduced from 4.791 to 4.711 times that of Armco iron at 35.6 degrees Fahr. (2 degrees Cent.) After aging at room temperature 300 hours, the hardness had increased to 66.7, the length had decreased to 6.0280 inches and the electrical resistivity had decreased to 4.583 times that of Armco iron at 35.6 degrees Fahr. (2 degrees Cent.)

Because of the "age" hardening effect found in Armco iron after quenching, it was thought desirable to ascertain whether volume and electrical resistivity changes could also be detected. A bar of Armco iron $\frac{1}{4}$ inches square and 6 inches long was quenched from 1832 degrees Fahr. (1000 degrees Cent.) in iced caustic soda

solution after which its Rockwell "B" hardness was 77.2 its length 5.992, and electrical resistivity 1.015 times that of the standard Armco iron at 35.6 degrees Fahr. (2 degrees Cent.) After treating in boiling water for one hour, the hardness had increased to 82.6 and the electrical resistivity had decreased to 1.002 times that of the

Table XI
Effect of Low Temperature Treatment on Rockwell "C" Hardness of Steel C-3 in Quenched Condition

Quenched from	No.	As Quenched	Held 5 Minutes at		After Aging at Room Tem- perature for 500 Hours
			-100° C. -148° F.	-183° C. -297° F.	
860° C.	1	66.1	67.0		69.4
	2	66.3		67.0	69.6
900° C.	1	61.6	65.3		68.5
	2	61.8		65.2	68.6
1000° C.	1	59.6	63.7		67.1
	2	60.0		64.0	67.4
1100° C.	1	59.2	62.5		66.0
	2	60.0		62.0	65.9

NOTE: Hardness Figures are Averages of Four Readings.

standard Armco iron at 35.6 degrees Fahr. (2 degrees Cent.) The length remained unchanged. Thesis work at Case School of Applied Science carried on in 1923 under the direction of Professor Boylston showed that cold drawn Armco iron heated to 302 degrees Fahr. (150 degrees Cent.) increased in tensile strength, but *decreased* in electrical resistivity. It is thus seen that all of the results obtained on Armco iron accord with the overstrain hypothesis of "age" hardening.

These special experiments leave little to be desired with respect to the separation of the two hardening changes. The volume changes are not only in the direction anticipated, but the rapid "age" hardening in the high carbon steels is shown to be accompanied by a rapid shrinkage, thus indicating that carbide precipitation is the major change.

The electrical measurements indicate that the austenite transformation in carbon steel is accompanied by a decrease in resistivity. The carbide precipitation is also accompanied by a decrease in electrical resistivity. In the alloy steel, C-8, however, the transformation of the austenite increases the electrical resis-

tivity while the carbide precipitation decreases it. Here is a directional change which can be used in this steel to supplement the volume changes in interpreting the hardness changes.

Opposed to the view that carbide precipitates from freshly formed martensite at room temperature and more rapidly at higher temperatures is the evidence obtained by Honda¹² that quenched and untempered steel does not show the magnetic transformation point for cementite on heating past 419 degrees Fahr. (215 degrees Cent.) In the absence of other evidence this might be accepted as a tentative proof of the absence of carbide. In the face of all the existing evidence to the contrary, however, this evidence can now be given but little weight. In fact Honda and Idei¹³ now hold that "age hardening" of quenched steel must be due to the transformation of austenite, but they attribute the shrinkage to the simultaneous change of the martensite to troostite. If troostite thus forms below the temperature of the magnetic transformation temperature of cementite, carbide must also precipitate to accord with the prevailing views regarding the constitution of troostite.

The electrical resistivity changes associated with the age hardening of duralumin are peculiar. It might be expected that other electrical properties such as the magnetic properties of fine precipitates would also be peculiar. At any rate the negative evidence of the magnetic test must give way to the ever increasing positive evidence that carbide precipitates from freshly formed martensite even at room temperature. Many investigators now believe that carbide precipitates at 212 degrees Fahr. (100 degrees Cent.) The present authors believe they have definitely associated the changes at room temperature with those at 212 degrees Fahr. (100 degrees Cent.)

Recently Dearden and Benedicks¹⁴ have repeated and extended the work of Honda on the magnetization of steel at temperatures up to 752 degrees Fahr. (400 degrees Cent.) They do not accept the magnetic results as evidence of the absence of cementite, but suggest that at low temperatures a "magnetically free" cementite forms.

¹²Honda, *Journal*, Iron and Steel Institute, No. 2, 1918, p. 375.

¹³Honda and Idei, *Scientific Reports*, Tohoku Imperial University, Vol. 9, No. 6, 1920.

¹⁴*Journal*, Iron and Steel Institute, No. 1, 1926, Vol. 113, p. 413.

Conclusion

The authors have made an especial investigation of the changes in hardness of freshly quenched steel at, above, and below room temperature. In order to correlate hardness changes with changes in certain other properties some electrical resistivity and volume measurements were made.

Freshly quenched high carbon steel when maintained near 32 degrees Fahr. (0 degrees Cent.) does not change appreciably in hardness for several hours. It hardens if cooled or heated above this temperature. The hardening on cooling is relatively independent of *time* but depends on the *temperature* reached. The hardening is accompanied by an *increase* in volume. It is clearly due to austenite transformation. In one alloy steel tested the electrical resistivity *increased* when austenite transformed, but with carbon steel the electrical resistivity of martensite is apparently less than austenite of the same composition.

The hardening produced on heating above about 32 degrees Fahr. (0 degrees Cent.) is a *time-temperature* phenomenon. The higher the temperature the shorter the time required for a given small hardness increase, at least up to 212 degrees Fahr. (100 degrees Cent.) and presumably up to a somewhat higher temperature. At 122, 167, 212 degrees Fahr. (50, 75 and 100 degrees Cent.) the hardness rises to a maximum and then decreases with more prolonged aging. The time required to reach the maximum for any temperature is longer the lower the temperature. The capability of age hardening above 32 degrees Fahr. (0 degrees Cent.) is not lost by previous hardening produced by cooling below 32 degrees Fahr. (0 degrees Cent.) In fact, the "age" hardening at room and certain higher temperatures is greater after hardening by liquid oxygen. These two hardening effects not only obey different laws as to *rate of hardening* but they are *additive*. The maximum hardness is obtained therefore by allowing both changes to take place. A higher hardness value is obtained by allowing the retained austenite to transform prior to aging than vice versa. This and other observations suggest that the "age" hardening is largely in the martensite. The "age" hardening at room and higher temperatures is accompanied by *decrease* in volume and decrease in electrical resistivity. The maximum Rockwell "C" hardness values obtained on the carbon steels were 70.1

on a 1.23 per cent and 70.2 on a 1.58 per cent carbon steel. The steels were quenched from 1562 degrees Fahr. (850 degrees Cent.) in iced caustic soda solution, immersed in liquid oxygen and then aged 150 hours at 122 degrees Fahr. (50 degrees Cent.)

In the interpretation of the hardening by cooling freshly quenched high carbon steel below about 32 degrees Fahr. (0 degrees Cent.) only the orthodox cause has been considered, namely, the conversion of soft austenite to hard martensite. Three factors are considered to account for the hardening of freshly quenched high carbon steel above about 32 degrees Fahr. (0 degrees Cent.) and up to 212 degrees Fahr. (100 degrees Cent.); (1) austenite conversion, (2) recovery after "overstrain," and (3) carbide precipitation. After considering the available evidence, the authors conclude that factors 1 and 2 are at most only minor and that the major changes including age hardening are due to carbide precipitation. The correctness of this conclusion is of course all important in connection with one of the most fundamental subjects in the art and science of steel treating—the constitution and nature of martensite.

Acknowledgement

The authors wish to express their indebtedness to the U. S. Bureau of Standards for the immersion of specimens in liquid hydrogen, to J. V. Emmons for supplying certain samples of steel and to A. B. Gladding for assistance in connection with the experiments on electrical resistance and volume changes.

DISCUSSION

R. S. DEAN: I would like to offer a few comments on this paper. In the first place, I wish the authors would train my Rockwell machine to behave so that I could read it regularly to two-tenths of a point or something of that nature. I notice that they call 73 to 79 in Armeo iron a large change in Rockwell reading, while that is just about the time I am beginning to believe there is a change.

I have not had an opportunity to digest the data as much as I would like to, but there is one possibility that may not have been fully eliminated, that is hardening due to some constituent other than carbon separating to give an age hardening. It appears that most of the data obtained could be accounted for by such a constituent which over-ages at room temperature. Yesterday, in the discussion of the paper by Grossmann and Snyder, I presented some ex-

perimental data we obtained on pure iron, and electrolytic iron melted in vacuo, in which we got no hardening after cold working and reheating, while on an electrolytic iron which was melted in air, we did get a very appreciable hardening after cold working and reheating. Also the electrolytic iron melted in air, which showed hardening by heating after cold working also showed a very appreciable hardening if we heated it to 500 degrees Cent. and quenched it and then reheated it to 350 degrees Cent., with no cold working intervening. We got an increase in hardness there from something like 70 B-scale Rockwell up to 92 B-scale Rockwell, or a hardness increase of twenty-two numbers on the B-scale. The microscopic evidence indicated that some constituent was separating in that range. It may be nitrogen or it may be oxygen or it may be something else.

I wondered if the effect of this liquid air immersion could not be explained by the effect of rate of cooling on the rate of precipitation. In age hardenable alloys we know that the more rapidly we cool them, the more rapidly we get age hardening and the greater that hardening it. Now, if the constituent separating here is one which over-ages at room temperature, the immersion in liquid air is effectively a quench, a quench of about—183 degrees Cent., and I wonder if that is not necessary to make this hardening take place more rapidly, the same thing being accomplished by a quench as we accomplish in cold work. For instance, in lead-antimony alloys we know that if we let them stand at room temperature, they will stand there for certainly over a year before we will get a solubility below half of one per cent antimony, as indicated by conductivity measurements, while if we cold work them, they will drop down so it is a matter of days only.

Without having had time to critically consider all these data, I wondered if these effects of various treatments on rate of precipitation might not account for most of the effects observed.

There was one other item in the matter of technique that I wanted to ask about, and that is as to how you could immerse a thing in liquid air and measure its hardness within two minutes after it was taken out and be sure it was back up to room temperature. There is a considerable difference between the hardness at liquid air temperature and the hardness at room temperature, and, even with a small piece, I do not quite see how one could be sure that, within two minutes, it reached room temperature.

A. S. TOWNSEND: At the request of Mr. Sykes we made Rockwell tests in our laboratory on six small blocks of steel which had been treated by him. The results of our determinations are given in the following table:

Rockwell Number			Rockwell Number		
#1	C	70.0	#2	C	70.2
		70.2			70.0
		70.2			70.4
		70.0			70.8
<hr/>			<hr/>		
Ave.	70.1	70.1	Ave.	70.3	70.3

#3	70.4		#4	70.6	
	70.4			70.4	
	70.6			70.2	
	70.2			70.4	
	<hr/>			<hr/>	
Ave.	70.4	70.4	Ave.	70.4	70.4
#5	70.4		#6	70.2	
	70.8			70.0	
	70.4			70.2	
	70.4			70.6	
	<hr/>			<hr/>	
Ave.	70.5	70.5	Ave.	70.3	70.3

These six pieces, Mr. Sykes stated, were his steel number C-9, quenched from 850 degrees Cent., immersed in liquid oxygen and then aged at + 50 degrees Cent. for 150 hours.

R. S. ARCHER: Mr. Chairman, I think Mr. Dean pointed out a very significant thing when he said that he wished he could make hardness tests with the consistency shown by the ones given by Mr. Sykes. Those who have studied or will study this paper in detail will realize the beauty of these results from the standpoint of consistency and precision, and that the whole research has depended to a large extent on the technique with which these specimens were hardened, prepared and tested. We might also say that the development of the Rockwell testing machine has been a great help in this kind of work.

I have naturally been especially interested in this research because of having speculated at various times on the phenomena involved. Mr. Sykes might have prefaced his presentation with a brief discussion of the status quo, which, briefly, and in part, is this,—that there have been scattered observations for many years to the effect that hardened steel exhibits a very slight additional hardening on aging at room temperature, or at slightly elevated temperatures. The actual occurrence of this hardening has been questioned, but recently there has been plenty of confirmation of the fact.

There has, however, been a great difference of opinion as to the cause of this hardening on aging, or slight reheating. The two principal views have been, first, the one proposed by Dr. Jeffries and myself that the hardening is caused by carbide precipitation; and the other view that the hardening is caused by the transformation of additional austenite to martensite. The work just reported by Mr. Sykes and Dr. Jeffries, I believe, was designed largely to answer that question, and by correlating the hardness changes with volume changes and by using the liquid air immersion as a preliminary to the aging treatments, it seems that they have shown quite definitely that this hardening is due to something in the nature of precipitation rather than to further transformation of austenite to martensite. The hardening on aging, for example, is accompanied by a volume contraction, whereas the austenite to martensite transformation is

accompanied by expansion. Furthermore, immersion in liquid air produces more martensite and also a greater capacity for age hardening, indicating that it is the martensite which undergoes the age hardening.

I merely wished to call attention to some of this background and to express my own appreciation of the experimental methods as well as the conception underlying this work.

DR. ZAY JEFFRIES: In connection with this interpretation of "age" hardening, in Dr. Honda's laboratory they seem to be firmly convinced that this hardening is due to transformation of further austenite, but as recently as December, 1926, a paper has come from Dr. Honda's laboratory by Tamaru showing that the volume decreases during the aging of steel. He attributes any hardening which is observed to the fact that some austenite transforms, which, although producing an increase in volume, does not compensate for the decrease in volume caused by what he calls transformation of the martensite to troostite. But in view of the fact that hardening can be due to precipitation, and, in fact, that we would expect hardening by precipitation, the other view seems rather strained and unnecessary.

In connection with the hardening due to immersion in liquid oxygen, and at other low temperatures, the specimen is taken out of the liquid oxygen and warm water is allowed to run over it. The first thing that happens is that the specimen is coated with ice, and in a very short time the ice melts and then the specimen is immersed in ordinary water. The specimen is held in the hand at the time of its Rockwell measurement and there could not be much question about its temperature. It is also a small specimen, a quarter inch square by a half inch long, so that it does not take long to reach room temperature in a liquid medium.

With reference to the precipitation being due to something other than carbon, I think that one of the things that this research has done quite definitely is to carry the changes going on at 100 degrees Cent. continuously and progressively down to room temperature and out of existence below room temperature. There is considerable carbon in these steels, one per cent or more in all of them, and much of the carbide is not in a visible or detectable form after the quench, and after certain heat treatments, like heating to 500 or 600 degrees Cent., it is observable under the microscope. The carbide must change in particle size as the temperature is increased in some way, and at some temperature it must, if it is in solution, precipitate or, if it is not in solution, begin to grow in particle size. Having found that in a freshly quenched piece of steel held at about zero degrees Cent. we get none of these changes, and then finding that changes take place to different extents and at different rates as the temperature is raised gradually up to 100 degrees Cent., it seems quite clear that there is no discontinuity in these changes.

In view of the magnitude of these changes, and in view of the very considerable change in electrical resistivity, a very considerable change in volume, a very definite change in hardness, the continuity of these changes, and the variation in rate of change with change in temperature, it would

seem more logical to attribute the room temperature changes to carbide precipitation rather than to some other change.

It is very interesting, however, to consider the case of the Armeo iron. The figures which Mr. Sykes gave were averages of some forty readings and the changes found there are not attributable, according to our results, to carbide precipitation, and there is no measurable volume change. There is, however, a decrease in electrical resistivity, and it might very well be that that change is due to nitride precipitation or something else, as suggested by Dean, and it might also be in the high carbon steels that nitride precipitation is going on simultaneously with the carbide change.

With reference to the pure iron, we obtained no hardening effect on quenching and aging. If there is to be a hardening effect due to precipitation, we should find that without the help of cold work. Cold work may hasten it or it may permit it to take place at a lower temperature, but I do not know that we can look to cold work to actually reveal the presence or absence of such a change.

Now, as regards the effect of liquid air immersion, it seems quite clear, I think, that that change is only a continuance of the changes which have started at some higher temperature in the transformation of austenite to martensite. A piece of steel is heated to a high temperature and quenched. At some temperature around 200 degrees Cent., under certain conditions, the austenite begins to break down, forming martensite. As the cooling progresses down to room temperature, that transformation has gone to a certain degree of completion, but is not completed. Carry the temperature on down to zero degrees, which was the temperature of the quenching bath in consideration, and the transformation proceeds to a definite extent and stops. The specimen can then be slightly heated without any further transformation of the austenite, in fact, it can be heated considerably, even up to 100 degrees Cent., without any further substantial change of the austenite. But it cannot be cooled a single degree further without more of the austenite transforming. So, at zero degrees Cent. we have a dividing line where the material has been caught in a state of transition, the transformation is mostly completed in carbon steels but is not mostly completed in some of the alloy steels at zero degrees Cent. If we continue the cooling on down to minus 100 degrees Cent., the transformation completes itself as far as it can, due to cooling. It does not always complete itself, but it completes itself as far as cooling will complete it. That is suggested by the fact that the Bureau of Standards immersed some of these specimens having only 35 Rockwell hardness after the quench down to the temperature of liquid hydrogen, and the increase in hardness was very slight, only the same as it was by liquid oxygen, or minus 100-degree Cent. immersion, showing that probably no degree of cooling will make that transformation go any farther.

So, having the steel trapped in a state of transit at zero degrees Cent. we can harden it by cooling it or we can harden it by heating it. If we harden by cooling, the hardening takes place in an instant; time is of no moment; if you simply cool it, the transformation progresses as far it will at that particular temperature. But if we harden by heating, we must comply

with certain time-temperature relations, which follow in every qualitative way the conditions observed in the age hardening of certain other alloys.

The hardening takes place very substantially at room temperature in a short time. This is another thing that the present research has brought out, namely, the extent of the hardening which we have obtained is considerable as compared with other results. That is because our hardness measurements were made immediately after the quenching and we have not measured any age hardening in our first results. Even waiting an hour before the test, as seen from the curves, would have lessened the apparent degree of age hardening.

R. S. ARCHER: Mr. Chairman, I would like to add another point on this paper of Sykes and Jeffries. I understand Mr. Dean to suggest that the increased age hardening which is possible in specimens that have been cooled in liquid air after quenching in the ordinary manner might be attributed, perhaps, not to the presence of more martensite, as proposed by Sykes and Jeffries, but to an accelerated rate of aging at room temperature due to the quenching from room temperature to liquid air.

It seems to me that this possibility is precluded by the fact that the increased amount of age hardening also occurs at elevated temperatures, such as 50 degrees and 100 degrees Cent. At these higher temperatures, it is clear that the age hardening goes to completion either with or without prior immersion in liquid air, because the hardness curves pass through maxima. Mere acceleration of the aging process would not, therefore, give higher values.

CHAIRMAN J. A. MATHEWS: I would like to ask one question of Mr. Sykes and Dr. Jeffries. As I understand, in quenching, the greatest dispersion of the carbon or carbides is supposed to correspond with the maximum hardness, and presumably lack of ductility. They state that where the carbides have coalesced in larger particles, clear up to annealed steel, we have a soft and ductile condition.

Now, in connection with the question brought up here in an earlier paper by Mr. Allen, the fact that steel can be cold-straightened immediately after quenching was mentioned, and why is it that steel with the maximum dispersion of the carbides can be cold-straightened while in a few hours after it is age hardened, when it seems to have acquired a set like cement, it cannot be disturbed. Has the work that you have been doing any bearing upon that? It is true of high speed steel and it is true of tool steel, it is true of tungsten magnet steel. Shortly after hardening, when the carbides presumably have precipitated or coalesced, you cannot do it. Does your work bear any reference to that?

DR. ZAY JEFFRIES: That phenomenon may have two aspects. What you call immediately after quenching in a commercial piece may involve a time so short after the quenching that the piece has not reached room temperature, in which case there is considerable austenite present, which should be capable of undergoing plastic deformation with much greater ease than the martensite.

The work which we have done would indicate that immediately after the full quench and full cooling, complete cooling, the hardness of a 1.23 per cent carbon steel quenched from 850 degrees Cent. is about 64.7 Rockwell, in other words, quite hard. But it would also indicate that precipitation of carbide

has not progressed very far. Now, that material would be expected to deform easier than the material after some age hardening, but whether enough easier to account for this straightening, I do not know.

On the other hand, the same phenomenon is encountered in the heat treatable aluminum alloys. Duralumin is an aluminum alloy which ages at room temperature after quenching. It can be deformed quite easily within a few minutes or a half hour or an hour after the quenching, whereas if allowed to stand a few hours at room temperature before the forming operation is attempted, it may crack and break to pieces. In that sense it is seen that the precipitation greatly defeats formability. I would suspect, however, in the case of the steels, that they may be still a bit warm when the forming operation is applied, in which case the greater amount of deformability is due to the presence of more austenite.

A thing which perhaps we have not appreciated sufficiently is this, that had we stopped our quenching experiments at, say, 50 degrees Cent. instead of zero degrees Cent. we would have retained more austenite. Had we stopped the quenching at minus 100 degrees Cent., of course, we would have retained less austenite. The amount of austenite that is transformed during the cooling after the temperature has once been reduced to, say, 200 degrees Cent., does not seem to depend very much on the rate of cooling; the material can cool slowly after that and the austenite transforms more gradually. If the material is cooled rapidly, then the austenite transforms more rapidly. Therefore, if a piece is taken out of the quenching medium while it is still warm, it contains more austenite than it does after it is cooled definitely down to room temperature.

CHAIRMAN J. A. MATHEWS: How was your Rockwell machine standardized? What would that test block test on your testing machine?

DR. ZAY JEFFRIES: The test block is relatively large as compared with these specimen, and the variation in hardness is greater than the variation in the hardness of the steels used in this investigation. In fact, these pieces of steel were prepared in a small size with the idea of getting great uniformity, and the spread in maximum and minimum reading obtained by the Rockwell people on specimens sent to them by Mr. Sykes was only five-tenths of a point in 24 readings. In other words, these blocks should make splendid Rockwell standards, not only around 70 hard, but, with proper treatment, at lower hardness values.

DR. H. STYRI: I would like to ask one question. Did you examine with the X-ray or any other means to determine if there was any austenite in the material which had the maximum hardness?

DR. ZAY JEFFRIES: No, we did not, but Scott has performed more drastic aging treatments than we did, at a somewhat different temperature, but he has heated about a week at 100 degrees Cent., and then on reheating to 260 degrees Cent. or thereabouts, he obtained the typical changes due to austenite transformation. I have no doubt that steel which is 70.2 hard, when heated to 260 degrees Cent. or thereabouts, would show a definite change due to austenite transformation. It would not, of course, show as great a change as the specimen which was not immersed in liquid oxygen.

December

SEGREGATION OF DISSOLVED ELEMENTS AND ITS INFLUENCE UPON CARBON DISTRIBUTION IN STEEL

BY E. G. MAHIN AND H. J. DILLON

Abstract

A brief account is given of the theories that have been advanced to explain the common coincidence of non-metallic inclusions and proeutectoid ferrite or cementite in annealed steels, these theories being classified as mechanical, chemical and physical. Attention is given to the work of one of the present authors and his students, and additional experimental evidence is cited to support the theory that slight solubility of most inclusions in austenite, with resulting contamination of microscopic zones surrounding these inclusions, is responsible for changes in phase relations, the excess of the proeutectoid phase being precipitated first in these regions. Thus segregation of dissolved impurities causes weakness, first because of the irregularity in composition with respect to these impurities, second because of ferrite segregation which is a consequence of such irregularity. It is believed that one of the most important of future advances in the science of steel making must result from a more thorough study of the influence of nonmetallic inclusions, and of methods for reducing to a negligible degree the size and number of such foreign particles unavoidably left in the finished product.

LACK of homogeneity is one of the very common sources of weakness in metals—or, indeed, of materials in general. However scientifically the engineer may design his machinery or structural material, with a view to uniform distribution of stresses when the piece is in service, unless the material composing the piece possesses uniformity of stress resistance, the maximum strength qualities will not result. Because of this, extraordinary efforts are made to manufacture the structural material in such a way as to avoid, to the highest possible degree, heterogeneity of structure or composition.

A paper presented before the ninth annual convention of the society held in Detroit September 19 to 23, 1927. Of the authors, who are members of the society, E. G. Mahin is professor of metallurgy and H. J. Dillon a graduate student at the University of Notre Dame, Notre Dame, Indiana. At date of publication, H. J. Dillon is assistant metallurgist, Inland Steel Co., Indiana Harbor, Indiana. Manuscript received August 15, 1927.

In the case of alloys, including all varieties of steel, entire homogeneity is an impossibility. Even theoretically, no alloy can be uniform in structure or composition except when the system is in a state of perfect solution. There are numerous nonferrous alloy systems which maintain this condition when slowly cooled into ordinary temperature ranges. But any steel, whether carbon or alloy, loses its homogeneous character as soon as it cools past a temperature of saturation for any phase—i. e., a transformation point—and thereafter it is by nature a segregated system. Of course this is an expected result of slow cooling for annealing and the only effort in such a case is to carry out the thermal treatment in such a manner as to produce a fine grain, so as at least to approach something like uniformity of structure.

An exception might be made to the above statement when we remember that martensite is harder and stronger than austenite of the same chemical composition, and in view of the now generally accepted idea that martensite is a sub-microscopic conglomerate. But it is at least true that lack of homogeneity of microscopic or macroscopic character generally gives a material of poorer strength characteristics than would otherwise be the case.

If it were possible (as it is not, practically) to produce a perfectly clean carbon steel, absolutely free from discrete particles of undissolved nonmetallic character, the problem would be a comparatively simple one, except for slowly cooled material. In the latter case the comparative weakness of the pearlite-ferrite or pearlite-cementite conglomerate is reduced by grain refinement, without corresponding loss of desirable ductility and without the development of internal stresses ordinarily attendant upon the formation of martensite or troostite by quenching. Many of the foreign elements of steel, whether intentionally added or present as necessarily incident to the process of manufacture, segregate as a natural consequence of the transformation, either remaining dissolved in the ferrite phase or forming carbides and entering the cementite phase. Examples of the former are nickel and silicon, of the latter chromium and manganese.

Such segregation as that just mentioned is a natural and unavoidable one, except as transformation may be retarded by quenching. And again its effects upon strength characteristics are minimized by modifying thermal treatment to promote refinement of grain.

Quite other elements dissolve in it is this type of several phases of partly soluble

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¹Revue de Métallurgie

²The Metal

³Mahin: Jour

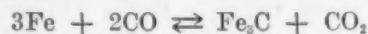
Quite otherwise is segregation, *within a single phase*, of the elements dissolved in and forming a constituent of that phase. And it is this type of segregation, as well as undue segregation of the several phases as units, and caused at least in part by the presence of partly soluble inclusions, that is here to be discussed.

The coincidence of nonmetallic inclusions and proeutectoid ferrite in annealed hypoeutectoid steels is not at all a matter of recent observation. This phenomenon has been noticed from the beginning of the science of metallography. And there has been added the observation that proeutectoid cementite exhibits a similar tendency to segregate with inclusions. But the various attempts that have been made to explain such observations have been so varied and so contradictory in nature as to bring about a condition little short of chaos. There would be little profit in a complete account of the various theories that have been proposed in this connection. But such theories may be roughly classified as follows:

(1) *Purely mechanical*.—This would include Ziegler's theory¹ that discrete particles act as nuclei for ferrite crystallization from austenite, cooled to Ar_3 , and Howe's proposition² that ferrite and inclusions are simultaneously rejected to austenite grain boundaries, as the steel cools through the transformation range.

Ziegler's theory has never been generally accepted and the conception of Howe has been repeatedly disproved³ by experiment.

(2) *Purely chemical*.—In this connection one may notice Giolitti's theory that nonmetallic inclusions have no effect whatever upon ferrite segregation, except that due to interaction between "oxidized" inclusions and carbon. Briefly, Giolitti conceives that such inclusions, by reducing the carbon concentration in their immediate vicinity, serve to start ferrite separation at these points when Ar_3 is reached. He argued that the well known fact that steels contain certain quantities of dissolved gases is responsible for the reversible reaction within the body of the steel:



the equilibrium of which is shifted in either direction, according to whether the piece is bathed in oxidizing or reducing gases. The oxidized inclusion would be supposed to reverse this reaction to

¹*Revue de Métallurgie*, 8, 1911, p. 655.

²"The Metallography of Steel and Cast Iron," p. 280.

³Mahin: *Journal of Industrial and Engineering Chemistry*, 11, 1919, p. 739.

some extent, thus causing the appearance of a thin sheath of ferrite about the inclusion, which would then act as a nucleus for further ferrite crystallization. On the other hand, if the steel were heated in a reducing atmosphere the resulting penetration of carbon monoxide would be expected to promote the direct reaction and thus to prevent ferrite segregation of this kind. Giolitti heated⁴ steels in carbon monoxide for 24 hours and reported that ferrite no longer showed any tendency to segregate about inclusions.

This conclusion has been discussed and experimental evidence cited⁵ to show that such treatment did not destroy, or even appreciably lessen, ferrite segregation about inclusions. It was also pointed out that such a theory did not serve to explain the almost universal appearance of manganese sulphide in ferrite grains, or the observed co-segregation of cementite and nonmetallic inclusions.

(3) *Purely physical*.—Stead disputed⁶ all theories that attribute to nonmetallic inclusions any direct effect upon carbon distribution. He advanced the idea that phosphorus segregation takes place during solidification of the ingot and that both phosphorus and nonmetallic inclusions are found in the last austenite to crystallize when the solidus is reached during cooling. According to Stead, high-phosphorus regions are also regions of premature ferrite separation, due to the tendency of carbon to withdraw from these portions. As the inclusions are also found here they naturally, for the most part, occupy places in ferrite grains (in "ghosts," when the ingot is rolled), rather than in pearlite. And as phosphorus is a very sluggish element, as to migration when the steel is heated, no ordinary treatment will serve to restore uniformity of phosphorus distribution, ferrite segregation being therefore very persistent.

It has been shown in one of the papers already cited⁷ that uniformity of phosphorus distribution can be accomplished by very long heating, but that ferrite segregation about inclusions was afterward fully as pronounced as before. Also, working with rolled stock and treating with copper reagent, it was found that, while inclusions do usually lie in high-phosphorus streaks, numerous instances

⁴Ann. chim. applicata, 2, 1914, p. 218; Intern. Z. Metallog., 7, 1914, p. 35; *Chemical and Metallurgical Engineering*, 20, 1919, p. 271.

⁵Mahin and Botts: *Chemical and Metallurgical Engineering*, 27, 1922, p. 980.

⁶*Journal*, Iron and Steel Institute, p. 58, 1900, 60; *Ibid.*, 91, 1915, 140; *Ibid.*, 97, 1918, 287 and 389.

⁷Mahin: loc. cit.

were observed zone of low-phosphorus streakly does exhibit property inhomogeneity of the ferrite.

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⁸Loc. cit., 1920, p. 1090; 1920, p. 1095.

⁹Mahin: L.

were observed where the inclusion was surrounded by a well defined zone of low-phosphorus ferrite, the whole lying within the phosphorus streak. It was concluded that, while phosphorus undoubtedly does exhibit the effect noted by Stead, there must still be some property inherent in the inclusion itself which affects the separation of the ferrite phase during cooling of the steel.

Mahin advanced the theory⁸ (a) that, inasmuch as no substance may be presumed to be entirely insoluble in any other, solubility being a question of degree only, the nonmetallic inclusion must therefore contaminate the metal in its immediate vicinity to a greater or less extent with its own substance, and (b) that any third component added to a binary solution (here iron and carbon) must necessarily alter phase relations so that separation of the supersaturating phase would (probably) take place earlier in these regions and thus cause phase segregation.

It was proved⁹ that while steel is above the transformation range carbon moves into the regions immediately in contact with the inclusion. From the standpoint of the phase rule this simply amounts to absorption of the ferrite phase by austenite. Whether carbon distribution is uniform in these temperature ranges is not known. But the theory states only that upon recooling, the contaminating elements or compounds promote ferrite separation and thus start crystallization of this phase around the inclusions. As A_{r_3} is a temperature of supersaturation, ferrite naturally migrates toward the nuclei so established.

Mahin and Hartwig showed that the local introduction of foreign elements, including both metals and nonmetals, caused ferrite segregation in these localities. Their method for preparing test specimens consisted in drilling clean holes in medium-carbon steel, then inserting plugs of other materials, including nonferrous alloys and steels similar to that of the body piece except that in each case one element of the insert was abnormally high. The assembled specimens were then heated to various temperatures for stated periods, followed by slow cooling in the furnace. Transverse sections were examined microscopically and it was observed that in nearly every case the line of contact was surrounded by a ring of ferrite. This ring was narrow in some cases, in others quite wide.

⁸Loc. cit., also Mahin and Hartwig: *Journal of Industrial and Engineering Chemistry*, 12, 1920, p. 1090; Mahin and Wilson: *Ibid.*, 15, 1923, p. 829; Mahin and Brewer, *Ibid.*, 12, 1920, p. 1095.

⁹Mahin: *Loc. cit.*

Elements found to cause such segregation included aluminium, copper, zinc, cobalt, chromium, tungsten, manganese, nickel, phosphorus, sulphur and silicon.

Mahin and Wilson called attention to the fact that hypereutectoid steels exhibit cementite segregation about inclusions, although this is usually not so marked as in the case of ferrite, partly because of the relatively small excess of cementite and partly because of the relatively slow migration of this phase. They remarked that this behavior is in harmony with the theory earlier advanced, as cementite is here the phase supersaturating the austenitic solution at Ar_3 .

Mahin and Brewer developed a method for testing microscopic areas for electrode potential and proved that a potential difference exists between the segregated ferrite ring and ferrite grains at more distant points, thus indicating a difference in chemical composition between such areas.

Finally Mahin and Botts called attention to the analogy between the corrosion rings surrounding manganese sulphide inclusions, so frequently observed on polished, but not etched, specimens and the antimony sulphide rings developed by treatment with the antimony reagent, thus indicating that sulphur actually exists in abnormal concentrations in these microscopic zones and that such sulphur segregation is largely responsible for the increased susceptibility to corrosion.

PURPOSE OF THE PRESENT INVESTIGATION

In the course of one of Stead's papers¹⁰ he described certain experimental work, in which a number of powdered materials were sealed into drilled cavities in steel, the specimens then being heated for prolonged periods. The foreign materials included quartz, magnesia, fluorspar, lime, basic slag, acid slag, titanium cyanide, mill scale and manganese sulphide. He reported that fluorspar was the only material which produced any evidence of ferrite segregation and concluded, as has already been stated, that inclusions are incidental to, rather than causes of, ferrite segregation.

In the light of results already mentioned, as obtained by the present author and his students, these results of Stead's seem to be inexplicable and it was with a view to obtaining further light

¹⁰*Journal, Iron and Steel Institute*, 97, 1918, p. 287.

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upon the general question that we decided to report Stead's work, with certain modifications.

EXPERIMENTAL

Two medium-carbon steels were used in the experiments. The first, containing 0.57 per cent carbon, was from stock in the laboratory. The second was a bar, carbon 0.54 per cent, furnished through the kindness of J. C. Dickson, chief chemist of the Inland Steel Co. Both steels were normal with respect to sulphur, silicon, phosphorus and manganese, as well as nonmetallic inclusions.

Specimens were cut about $1\frac{1}{2}$ inches long and $\frac{3}{4}$ -inch in diameter and drilled in the longitudinal axis to a depth of $\frac{3}{4}$ -inch. The desired powdered material was packed into the hole, then a plug of the same steel was driven in tightly and riveted firmly at the surface.

The following materials were ground to 120-mesh and were used as inclusions: (1) manganese sulphide, (2) ferrous sulphide, (3) ferromanganese, (4) ferroboration, (5) ferrosilicon, (6) blast furnace slag, (7) basic open-hearth slag, (8) mill scale.

Manganese sulphide was prepared by precipitating from a solution of manganese nitrate by the addition of ammonium sulphide. As the product oxidizes very readily in air it was washed by decantation with hot water, then filtered rapidly and dried under reduced pressure over soda lime. The surface of the mass, even under these precautions, was somewhat browned by oxidation but this was separated and discarded.

The ferrous sulphide was from material already on hand, while the other materials were furnished by Mr. Dickson.

The assembled specimens were heated under the conditions noted for each photomicrograph and cooled in the furnace. Transverse sections were cut and prepared in the usual way for microscopic examination, the etching being with nitric acid in alcohol.

The first trials with most of the specimens produced negative—or at most, minor—results, so far as observable ferrite segregation was concerned. In the case of manganese sulphide and ferrous sulphide inclusions some of the plugs blew out, indicating a possible volatilization of sulphur. It may here be remarked that this

absence of ferrite segregation around the cavity disposed of the possibility of other ferrite rings being due to decarburization by enclosed gaseous oxygen.

It was thought possible that contact between steel and included matter was poor and in order to remedy this defect, as well as to avoid the expulsion of plugs, subsequent specimens were taken from the furnace as soon as they had become heated to redness, then forged vigorously on the anvil. That failure to produce ferrite segregation had actually been due, in some cases, to lack of contact, was rather definitely indicated by the results.

DISCUSSION

Manganese sulphide.—A low-carbon zone, approximately $\frac{1}{2}$ -millimeter in depth and merging into the original structure, is found surrounding these inclusions. This is shown in Fig. 1. There can be no question of decarburization by oxidation here, for three reasons: (a) as already observed, before forging the specimens no segregation was found; (b) manganese sulphide is an active reducing agent, and thus a deoxidizer; (c) the minute amount of carbon that could be removed by enclosed oxygen would easily be replaced by migration from more distant points, during the heating period of 20 hours. Whether manganese sulphide dissolves in austenite as molecules of the compound or by atoms of manganese and sulphur taking a place in the crystal lattice, the evidence of solution seems conclusive.

Ferrous sulphide.—Figs. 2 and 3 show the effect of this included matter. As the iron of the compound is not different from iron already a part of the austenite, it is obvious that sulphur itself is the active agent here.

Ferrosilicon.—No change in carbon distribution was noted. Considering the results obtained by Mahin and Hartwig, using an insert of high-silicon steel, this is difficult to understand; but there may be here also a question of poor contact. Further experiments are in progress.

Ferromanganese.—Fig. 4 is typical of the results obtained with this alloy. As ferromanganese is a well recognized deoxidizer and carburizer, the appearance of a ferrite ring surrounded by a low-carbon zone, showing the action of segregated manganese, seems all the more remarkable.



Fig. 1.—Ph
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Inclusion, Heate
Photomicrograph
Cent.) for 15
at 1650 Degrees

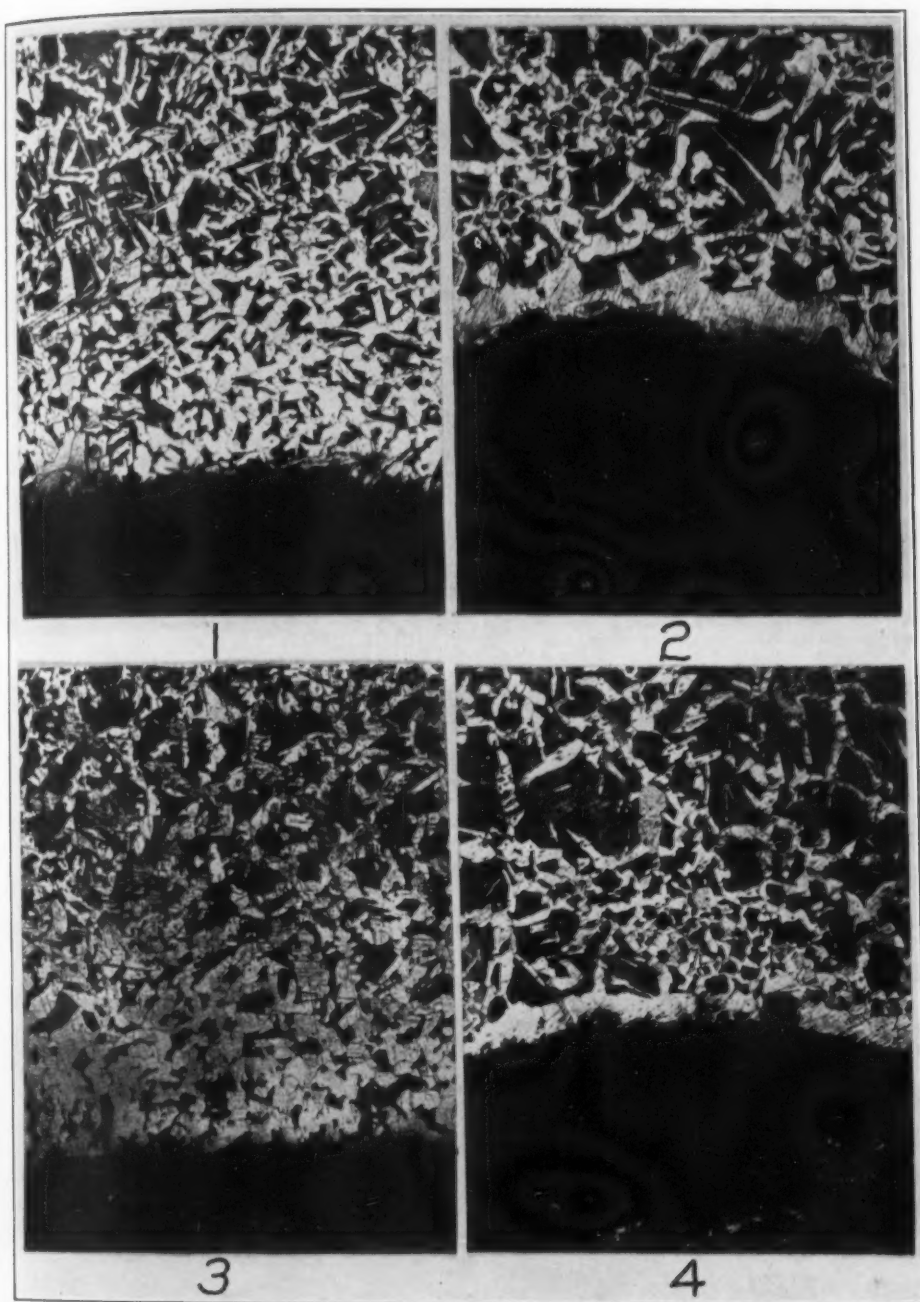


Fig. 1—Photomicrograph of Manganese Sulphide Inclusion, Heated at 1650 Degrees Fahr. (900 Degrees Cent.) for 20 Hours. 45 x. Fig. 2—Photomicrograph of Ferrous Sulphide Inclusion, Heated at 1650 Degrees Fahr. (900 Degrees Cent.) for 10 Hours. 45 x. Fig. 3—Photomicrograph of Ferrous Sulphide Inclusion Heated at 1650 Degrees Fahr. (900 Degrees Cent.) for 15 Hours. 45 x. Fig. 4—Photomicrograph of Ferromanganese Inclusion Heated at 1650 Degrees Fahr. (900 Degrees Cent.) for 5 Hours. Magnification 45 x.

The anomaly presented by the action of manganese and nickel was discussed in an earlier paper¹¹. The following is quoted: "This is an effect that at first appears to be inconsistent with the property usually attributed to these metals of lowering the transformation points of steel. If the temperature represented by Ar_3 for a given steel, is thus lowered, one would ordinarily interpret the action as that of increasing the ferrite solubility in austenite. In a steel containing segregated nickel or manganese it would then appear reasonable to expect that ferrite would separate in these centers of contamination last, instead of first, as the steel cools, which would then leave them in pearlite grains. This is directly contrary to the observed facts.

"We are unable to explain this apparent anomaly upon the basis of any direct experimental evidence, but we offer the suggestion that the localized ternary alloy produced by the invading metal, existing in direct contact with the binary solution, produces a system analogous to that of two dissimilar and immiscible solvents containing a common solute, in which the distribution ratio is not unity. Considered as the solvents in question, of course neither the iron-nickel nor the iron-manganese alloy is immiscible with iron above A_3 , but the comparatively low mobility of manganese and nickel has the same effect as immiscibility, except in the case of protracted heat treatments. Supposing that the distribution ratio for carbon in the two solvents (iron-nickel or iron-manganese and iron) is such as to cause a recession of carbon from the region invaded by the added (or segregated) metal, the transformation point of the system in this region will be the resultant of two opposing effects: (a) lowering, primarily due to the formation of the ternary alloy, and (b) raising, due to the diminished carbon content. It is conceivable that the latter effect may be more pronounced than the former, the net result in a cooling steel then being that the system existing at the centers of contamination will be the first to reach Ar_3 and that ferrite will be generated first in these regions."

Ferroboration.—The specimens containing ferroboration were exceedingly difficult to cut, after the heat treatment, when the region of the inclusion was reached by the hack saw. This was explained when the sections were examined microscopically. A definite incrustation was found on the walls of the cavity, this material tak-

¹¹Mahin and Botts: Loc. cit.



Fig. 5—
Hours. 90 x
Fahr. for 15
Carbide and
Represented by
Fig. 7—Photo
Degrees Cent.
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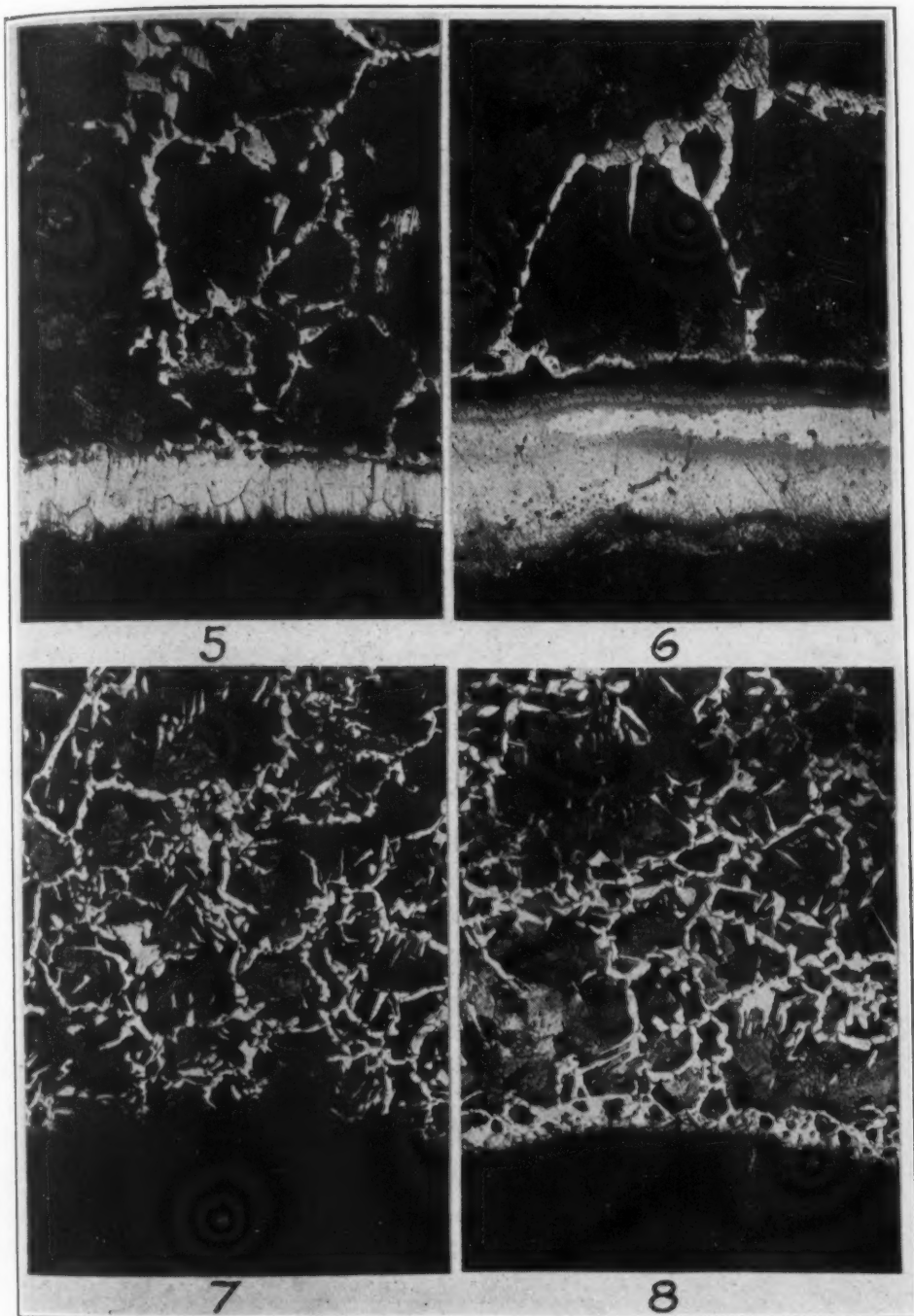


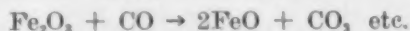
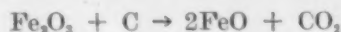
Fig. 5—Photomicrograph of Ferroboration Inclusion, Heated at 1650 Degrees Fahr. for 10 Hours. 90 x. Fig. 6—Photomicrograph of Ferroboration Inclusion, Heated at 1650 Degrees Fahr. for 15 Hours. Magnification 90 x. The Great Difference in Hardness Between Boron Carbide and Steel Caused Rounding Off at Contact During Polishing. This Shoulder is Represented by the Dark Band Separating Boron Carbide and Ferrite Ring in Figs. 5 and 6. Fig. 7—Photomicrograph of Blast Furnace Slag Inclusion Heated at 1650 Degrees Fahr. (900 Degrees Cent.) for 5 Hours, but Without Forging. Magnification 45 x. Fig. 8—Photomicrograph of Blast Furnace Slag Inclusion, Heated at 1650 Degrees Fahr. (900 Degrees Cent.) for 20 Hours. Piece Forged as Soon as Heated to Redness. Magnification 45 x.

ing a brilliant polish and remaining unattacked by the etching agent. It was assumed to be boron carbide, formed by the reaction of dissolved carbon and ferroboron. But outside this carbide ring and in the inner zone of steel is found a narrow ring of ferrite, joined by the ferrite net work of the body piece. This appearance is seen in Figs. 5 and 6.

Blast furnace slag.—This material gave no result, at first, as is indicated by Fig. 7. After forging the specimen as already described, and reheating for 20 hours, the result shown in Fig. 8 was obtained. Slag of this character might be presumed to have a very low solubility in austenite, with the possible exception of the sulphur contained in it, yet a definite penetration is indicated by the low-carbon zone surrounding the inclusion. Such penetration is indicated also by the alteration in grain structure of the steel in this zone.

Basic open-hearth slag.—The results are indicated in Figs. 9, 10 and 11. As this slag is usually classed as an oxidized material, decarburization of the steel by oxidation might be thought to have played some part in the ferrite segregation noted in these photomicrographs. This point is discussed below in connection with the results obtained by mill scale. For reasons there given, as well as for the obvious reason that such slag can be an active decarburizer only when the entire material, including the steel itself, is in a fused condition, such action in these experiments is thought to be very slight. Certainly carbon migration should serve to replenish that possibly oxidized, except in a very narrow zone at the inner surface of the cavity.

Mill scale.—The result of this treatment is shown in Fig. 12. As this material consists chiefly of ferric oxide it should certainly cause some oxidation of carbon, where contact is good. In fact, the appearance of the light gray material found in the cavity after sectioning suggests the reduction to ferrous oxide, which would be accomplished by both iron and carbon of the steel. A series of reactions like the following would be expected:



Also

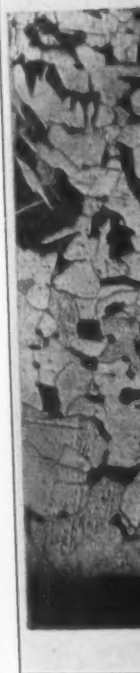
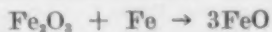


Fig. 9—
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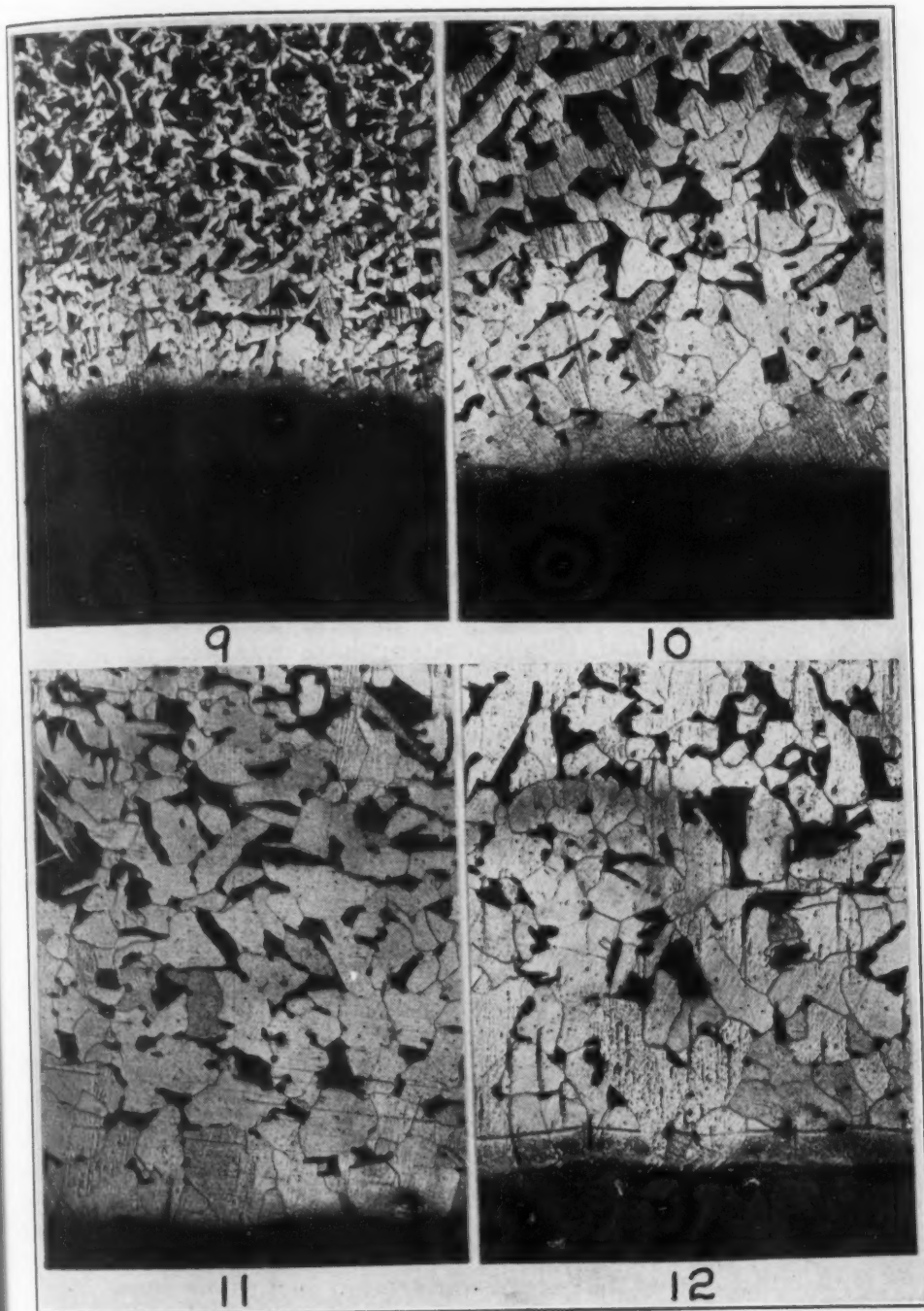


Fig. 9—Photomicrograph of Basic Open-Hearth Slag Inclusion, Heated at 1650 Degrees Fahr. (900 Degrees Cent.) for 15 Hours. Magnification 45 x. Fig. 10—Photomicrograph of Basic Open-Hearth Slag Inclusion, Heated at 1650 Degrees Fahr. (900 Degrees Cent.) for 15 Hours. Magnification 90 x. Fig. 11—Photomicrograph of Basic Open-Hearth Slag Inclusion, Heated at 1650 Degrees Fahr. (900 Degrees Cent.) for 20 Hours. Magnification 45 x. Fig. 12—Photomicrograph of Mill Scale Inclusion, Heated at 1650 Degrees Fahr. (900 Degrees Cent.) for 15 Hours. Magnification 90 x.

This, of course, is about what goes on during some processes of malleableizing castings. But it should here be noticed that in malleableizing processes the supply of oxygen is practically inexhaustible, so that outward diffusion of carbon can never equalize carbon removal near the surface. Also the oxides of carbon pass freely outward and escape.

Quite otherwise is the case in these experiments. The included material is tightly packed and confined in a small cavity. Except at the very first, gases may pass only in one direction—into the body of the metal. Whether the oxides of carbon can reach such a large concentration in such a relatively narrow zone as to cause decarburization so rapidly as to prevent its neutralization by carbon migration, is an open question.

The authors do not presume to answer this question. But they do suggest that the presence, in this limited zone, of abnormal concentrations of dissolved oxides of carbon, as well as (possibly) of dissolved oxygen itself, may have the physical effect already discussed at length—that they so alter phase relations as to cause premature precipitation of the ferrite phase and so start segregation.

No matter what element of truth may lie in any of these proposed explanations, the undoubted—and very important—fact remains that oxide inclusions are prolific causes of ferrite segregation. Probably most of the ferrous oxide inclusions often found in steel were originally enclosed as ferric oxide, the reduction being accomplished after contact with air was prevented.

McAdam's corrosion fatigue experiments.—At the Chicago meeting of this Society Dr. McAdam described¹² a very interesting and important series of experiments, as one result of which he concluded that corrosion, starting at nonmetallic inclusions, is a very effective factor in reducing fatigue resistance. The photomicrographs which he shows in his paper exhibit the same oxidation rings surrounding inclusions that have been discussed in the present paper, and in earlier papers already cited.

McAdam believes that corrosion around inclusions forms start-points for fatigue failures, a conclusion which seems quite reasonable and which is amply demonstrated by his experimental results. We believe also that even without corrosion the endurance limit is

¹²TRANSACTIONS, American Society for Steel Treating, 11, 1927, p. 355.

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Mahin's slide

probably a great deal lower than would be the case if inclusions were entirely absent, and that this is not all due to simple discontinuity of metal at the place occupied by the inclusion.

Consider, for example, the inclusion of manganese sulphide. If a chemical analysis of a steel shows a sulphur content of (say) 0.03 per cent, the steel is regarded as fairly good, in this particular at least. And yet it is a practical certainty that a considerable portion of the sulphur is present in the inclusion itself, and we have shown that much of the remainder (how much, we do not know) is segregated in a narrow zone surrounding the inclusion. The inclusion itself is undesirable but, after all, it is usually a body with a smooth surface, which is better than a rough microscopic cavity. But suppose, for the sake of argument, that the metal in its immediate vicinity has a sulphur content of 1 per cent, a figure which seems not unreasonable. This metal is weak and brittle and it forms the best (or rather the worst) possible starting point for a fatigue failure, even in the absence of corrosion. And similar reasoning will apply to most other segregated elements.

SUMMARY

Current theories concerning the co-segregation of inclusions and proeutectoid ferrite or cementite have been discussed. Further support is offered for the view that localized contamination of microscopic portions of metal by the inclusion is responsible, in large measure, for premature precipitation of the proeutectoid phase, thus starting local crystallization of this phase. In addition to this undesirable result, the metal in immediate contact with the inclusion is weakened, in most cases, by the contamination and this makes the presence of the inclusion doubly undesirable. It is suggested that this localized weakness may have much to do with fatigue failures. We believe that one of the most important, but as yet almost untouched, fields for useful research lies in a careful study of the effects of inclusions, and of methods for further reducing their prevalence in steel.

DISCUSSION

A. N. CONARROE: Something has occurred to me while looking over Mr. Mahin's slides, and I would like to ask him a question. He mentioned that the

specimens were cooled in the furnace. The microstructures apparently are the structures that would be given by a faster cool. I am wondering why they do not give the annealed structure there, or if he cooled them in a small furnace at a rapid rate.

E. G. MAHIN: These specimens were all cooled in the furnace, and I do not know just what structure Mr. Conarrore refers to as not being characteristic of the annealed specimens.

A. N. CONARRORE: They all seemed to give a normalized structure rather than the broader ferrite, generally found in annealed structures, that you get on slow cooling.

E. G. MAHIN: After the long heating periods of ten, fifteen and twenty hours, the specimens were cooled directly in a closed furnace.

MR. CLARK: I would like to ask the author of the last paper whether his study of inclusions would cause him to conclude that the difficulty that the steel manufacturers are having at present with free cutting screw stock is due to that hard zone caused by a chemical combination of several elements.

E. G. MAHIN: I think it would be making a rather broad statement to say that any such difficulty is due in all cases, or even in most cases, to inclusions. I do think, however, that the segregation of dissolved material around inclusions and the consequent segregation of carbon do make a very great lack of uniformity in hardness. It is of microscopic character usually, of course. But, of course, this one case that I mentioned of a very hard material, which we supposed was boron carbide, is unusual, just because we were using ferroboration as an inclusion. I don't think that I could answer that question in the affirmative, although I do believe that such segregations certainly are responsible for spot hardness and spot softness in many cases.

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RECENT EXPERIMENTS RELATING TO THE WEAR OF PLUG GAGES

BY H. J. FRENCH AND H. K. HERSCHMAN

Abstract

Results are given of tests made in a laboratory wear tester in gaging file-hard high carbon steel, an aluminum "piston alloy" and a cast iron. Of the various gage metals investigated chromium-plated gages showed the highest resistance to wear under conditions of metal-to-metal contact. Ammonia-treated chromium-aluminum steel, marketed under the name Nitalloy, was second in resistance to wear and much superior to the remainder of the group which showed variations but no radical differences in performance of the individual metals.

In tests made in file-hard high carbon steel in the presence of a non-metallic abrasive, Stellite, a high-carbon high-chromium iron alloy and chromium-plated gages showed better resistance to wear than the customary high carbon steels or the Nitalloy.

I. INTRODUCTION

IT was pointed out some time ago by the authors that considerable difficulty had been experienced in securing information concerning wear resistance of different metals from service wear tests of plug gages on account of the many variables normally encountered in shop gaging practice. It had likewise been exceedingly difficult to secure data which would adequately define the conditions under which the gages had been used. For these reasons it seemed necessary, in any study of the wear of plug gages, to first carry out experiments under the close control of gaging conditions which could be maintained in the laboratory. Any conclusion drawn may subsequently be checked by relatively few tests in actual service; in this case the test gages may be followed more closely than would ordinarily be possible with a large number of test specimens.

Published by permission of the Director, Bureau of Standards, Washington, D. C.

A paper presented before the ninth annual convention of the society held in Detroit, September 19 to 23, 1927. Of the authors, who are members of the society, H. J. French, is senior metallurgist and H. K. Herschman, assistant scientist, Bureau of Standards, Washington, D. C. Manuscript received June 21, 1927.

During 1926 a description¹ was published of the laboratory tester devised by the authors for the study of the wear of plug gages. This machine provides for the repeated lowering and raising (equivalent to insertion and removal) of the gages from split rings representing the "work"; contact pressure, presence of non-metallic abrasives, and other important variables are under control. Preliminary tests were reported with the description of the machine to show that reproducible results could be secured and that these were consistent, under certain conditions, with experience in practical service.

The reported tests were made in the presence of a non-metallic abrasive ("abrasive wear tests") and likewise under conditions where the gage rubbed directly in contact with the work ("metal-to-metal wear tests"). It was pointed out that the small differences in wear resistance shown in these tests by a number of hardened high carbon steels were quite consistent with results of service wear tests, also reported. Furthermore, in the laboratory tests as in practical service, chromium-plated gages showed a marked superiority in wear resistance over the steel gages.

These laboratory experiments were restricted to the gaging of file-hard high carbon steel and have since been supplemented by a study of the wear of different metals when gaging an aluminum piston-alloy and cast iron. The list of materials used for the test gages was likewise expanded to include a high-carbon high-chromium iron alloy, Stellite, and the ammonia-treated chromium-aluminum steels marketed in the United States under the name Nitralloy. These supplementary tests are the ones with which this report is mainly concerned, but some additional and more detailed information concerning the preliminary work in gaging the carbon steel is included.

II. TEST METHODS AND PROCEDURE

The test equipment and procedure employed in all experiments was the same as that described in detail in the report of preliminary tests to which reference has already been made. The metals gaged were (1) hardened high carbon steel, (2) an aluminum base "piston alloy", heat treated and aged, and (3) cast

¹H. J. French and H. K. Herschman: "Wear of Steels with Particular Reference to Plug Gages," *TRANSACTIONS, A. S. S. T.*, Vol. 10, No. 5, Nov., 1926, p. 683.

Chemical C

Carbon, total,
Carbon, graph
Carbon, comb
Manganese,
Phosphorus,
Sulphur, %
Silicon, %
Copper, %
Iron, %
Magnesium,
Aluminum, %

Size of casting

Rolled to bar

Heat treatment
before use in

Hardness, as
Rockwell "C"
Brinell 3000
Brinell 500
Microstructure

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Table I
Chemical Compositions and Other Details of the Metals Gaged in the Wear Tests

	1.05 % carbon steel	Aluminum "piston alloy"	Cast iron
Carbon, total, %....	1.06		3.21
Carbon, graphitic, %			2.41
Carbon, combined, %			0.80
Manganese, %.....	0.24		0.60
Phosphorus, %.....	0.014		0.355
Sulphur, %.....	0.016		0.038
Silicon, %.....	0.18	0.16	0.56
Copper, %.....		10.2	
Iron, %.....		1.3	
Magnesium, %.....		0.35	
Aluminum, %.....		Balance	
Size of casting.....		2" diam. × 15" long	1¾" diam. × 14" long (a)
Rolled to bars.....	2" diam.		
Heat treatment be- fore use in tests	1470°F water quench; temper 300°F	925°F 4 hrs, water quench; age in oil 1 hr. at 400°F.	none
Hardness, as used			
Rockwell "C" scale	64		
Brinell 3000 Kg. load			179
Brinell 500 Kg. load		81	
Microstructure	See Fig. 1.	See Fig. 1.	See Fig. 1.

(a) Pouring temperature for these castings approximately 2550 degrees Fahr.

iron. The chemical compositions of these metals and other details concerning them are given in Table I, while their microstructures are illustrated in Fig. 1.

The chemical compositions of the metals from which the gages were made are recorded in Table II, while a summary of the treatments of the test gages is given in Table III. Photomicrographs showing the depth and character of case in the Nitralloy gages are given in Fig. 2.

The term "file-hard" used in Table III and throughout the text, means resistance to penetration by new fine Swiss-type files

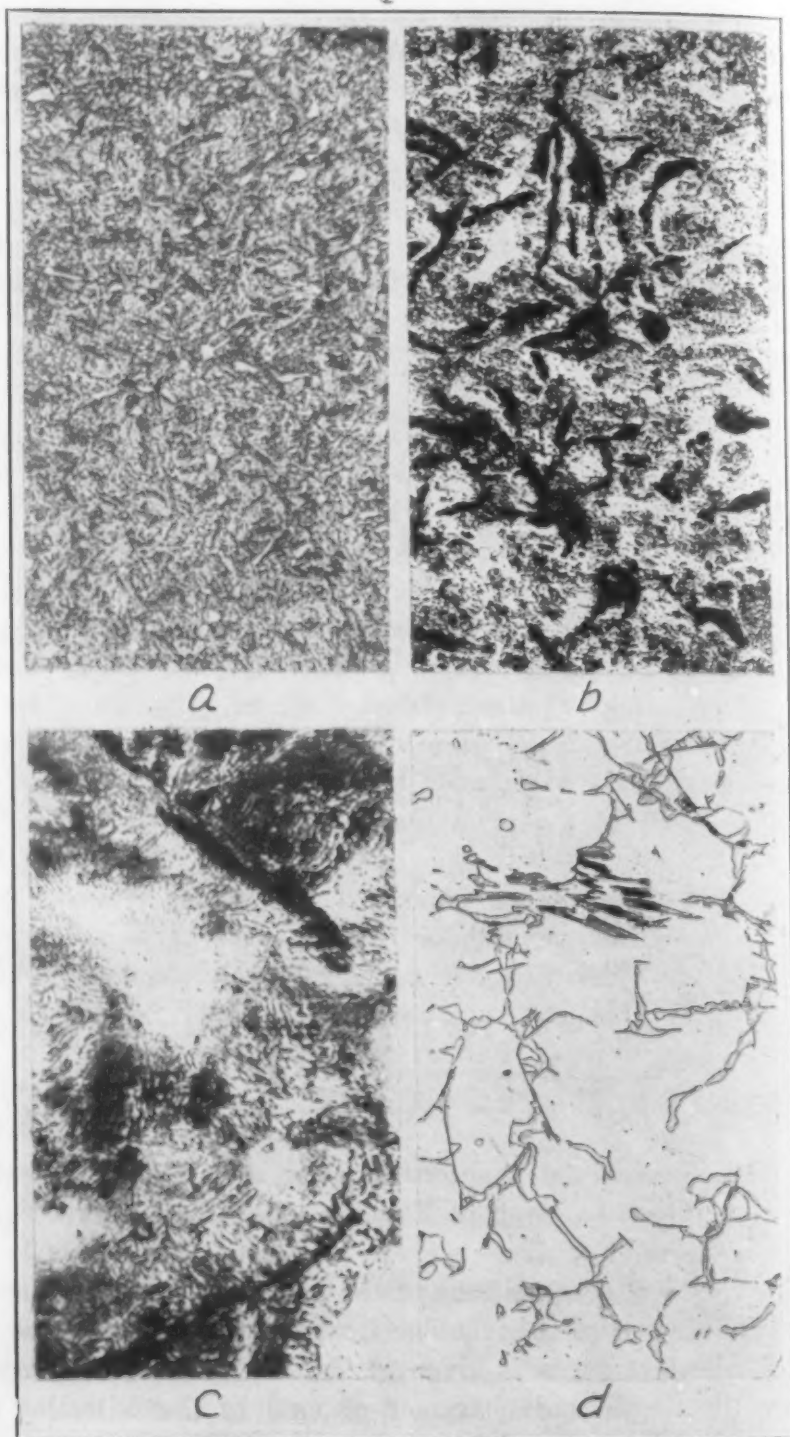


Fig. 1—Structures of the Metals Gaged.

A. 1.05 Per Cent Carbon Steel. Etched with 2 Per Cent Nitric Acid. 500 x.

B. Cast Iron. Etched with 5 Per Cent Picric Acid. 100 x.

C. Cast Iron. Etched with 5 Per Cent Picric Acid. 500 x.

D. Aluminum Alloy. Etched with $\frac{1}{2}$ Per Cent Hydrofluoric Acid. 100 x.

For details of Chemical Composition, Heat Treatment, and Properties of These Metals, See Table I.

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Material	
Nitr alloy	...
High speed	...
steel
Stellite
High-carbon-
high-
chromium
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Oil Hardening
tool steel
1.05% carbon
steel
Ball-race steel

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such as may be found in most machine shops. File tests are dependent upon a number of variables and are, therefore, not an accurate means of determining hardness. However, the terms "file-hard" and "file-soft" give a convenient method of reference widely used in industry. The properties of the test gages are more closely defined by the heat treatments and Rockwell

Table II
Chemical Compositions of the Metals from Which the Test
Gages were made

Material	Chemical compositions, per cent												
	C	Mn	P	S	Si	Cr	W	V	Al	Co	Mo	Ni	Fe
Nitr alloy ...	0.43	0.57	0.010	0.032	0.31	1.85		0.02	1.29				
High speed steel	0.75	0.31			0.11	3.92	17.95	0.89					
Stellite	2.87	0.76			0.70	32.5	15.7	0.02		41.1	0.13	1.12	4.1
High-carbon-high-chromium iron alloy .	2.06	0.38	0.020	0.010	0.31	11.45		0.03					
Oil Hardening tool steel .	0.86	1.17	0.021	0.010	0.21	0.51	0.41						
1.05% carbon steel	1.06	0.24	0.014	0.016	0.18								
Ball-race steel	1.01	0.21	0.016	0.034	0.29	1.46							

hardness numbers recorded in Table III for the different steels.

Two gages were tested for each condition of treatment in each of the three metals, high carbon steel, the aluminum alloy and cast iron. Except when otherwise indicated, the tests were metal-to-metal wear tests in which non-metallic abrasives were absent. Each gage was inserted 4000 times into the ring and the wear of the gage measured both by decrease in diameter near the entering end and by weight loss. The corresponding wear of the ring was determined by change in weight. This procedure was ordinarily repeated eight times so that comparisons of wear are based on 32,000 insertions of each of two gages making a total of 64,000 gagings.

III. EXPERIMENTAL RESULTS

1. *Diameter decrease of the gages.* The initial surface condition of a metal may play a large part in determining the wear produced under otherwise fixed conditions. The practice of subjecting ground or other machine-finished surfaces for a single short interval to the frictional forces producing wear may yield

Table III
Heat Treatments of the Plug Gages Made from the Various Metals. (For Chemical Compositions for these Metals Refer to Table II)

Material	Designated as	Heated		Cooled in	Reheated to, ° F.	Reheated in	for, hrs.	Rockwell Hardness ("C" scale) for gages			
		to, ° F.	in					Steel	Al. alloy	Cast iron	
								1	2	1	2
Nitralloy	Ammonia Treated	940	ammonia	96	not reheated		...	..	..	..	..
High speed steel	Hardened	2400(a)	air	1½ min.	1100	air	¾	66	64.5	64.5	64.5
Stellite	.....	....	Used as cast	....	....	....	....	..	..	..	..
High-carbon-high-chromium iron alloy	Hardened	1850	powdered charcoal	3½	300	oil	1	53.5	54	53	55
Oil hardening tool steel	File hard File soft	1515 1515	air air	½ ½	300 615	oil salt(b)	1 1	64 56	64.5 56.5	63 55	63 54.5
1.05% carbon steel	File hard File soft	1470 1470	air air	½ ½	300 not reheated	oil	1 ...	66 50	66.5 46.5	65.5 44	65.5 45
Ball race steel	File hard File soft	1470 1560	air air	½ ½	300 570	oil salt(b)	1 1	63 58.5	62.5 58.5	61 56	61 56

Deposited on 1.05% carbon steel, first water quenched from 1470° F. and tempered at 570° F.; lapped after deposition unless otherwise noted.

(a) Preheated for 20 minutes at 1600° F.

(b) Mixture of sodium and potassium nitrates.

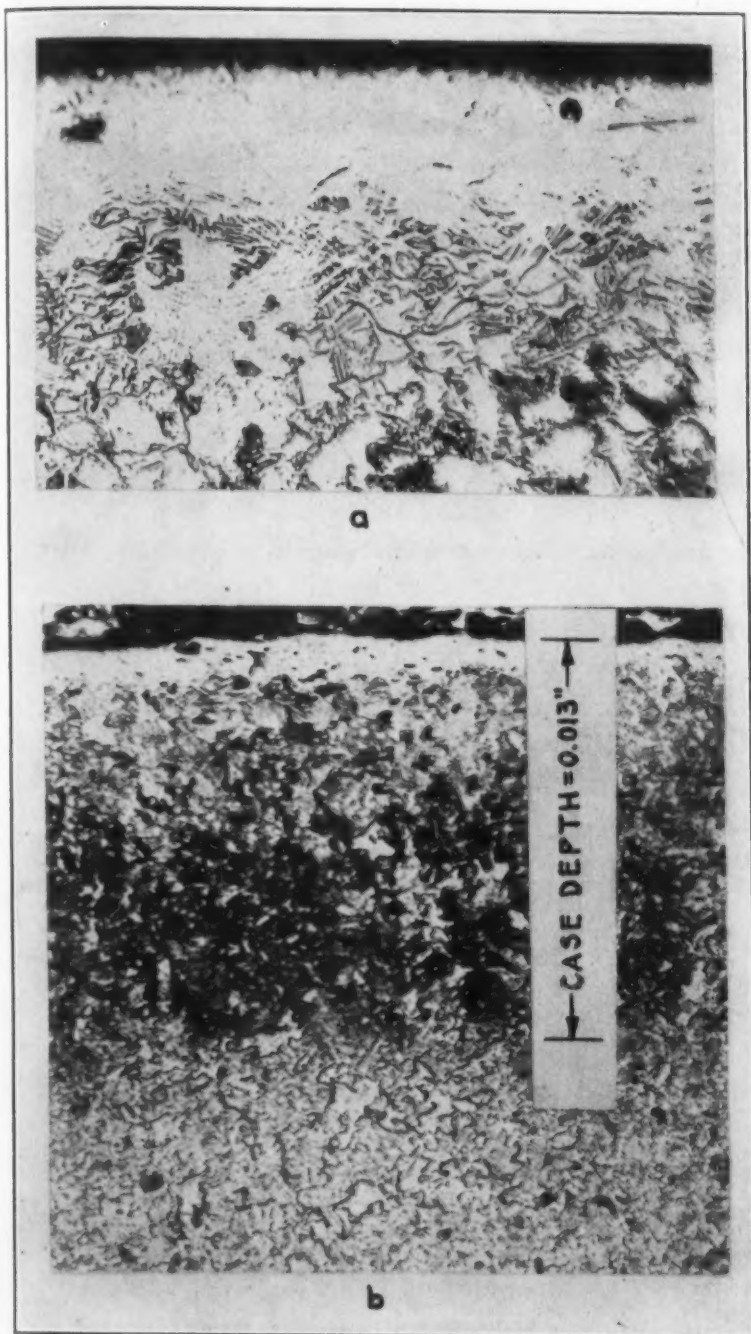


Fig. 2—Photomicrographs of the Case and Core of the Ammonia Treated Chromium-Aluminum Steel Called Nitralloy.

A. Shows Character of the Case at the Surface of the Gage. (Cross Section.) 500 x.

B. Shows Depth of Case and Character of the Core. 130 x. Samples Etched with 2 Per Cent Nitric Acid in Alcohol.

results which are very different from those which will be obtained in subsequent periods. Such effects have been found by McPharlin² to be of great importance in gages for close tolerance work and were likewise recently shown by one of the authors³ to be of major importance for bearing bronzes.

The primary object of the tests considered in this report was to develop information concerning the wearing properties of different metals for plug gages and not to determine the effects on wear of initial condition of surface or methods of finishing plug gages. Accordingly eight consecutive wear tests were made on each set of gages, as already described, to make reasonably certain that the results would be representative of the different metals and treatments selected and not solely indicative of the original finish of the gage. As shown in the relation between wear and total number of holes gaged, summarized graphically in Fig. 3, no appreciable "wearing-in" took place in most of the tests and, within limits of experimental accuracy, the wear is practically a direct function of the number of holes gaged. An exception is the high-carbon high-chromium iron alloy used in gaging the aluminum alloy. In gages made of this metal, a somewhat greater wear rate is observed at the start than in subsequent intervals and this is more noticeable than in most of the other tests shown in Fig. 3. In general, however, either the total wear in gaging 64,000 holes with the two gages or the average wear of the two gages per 32,000 holes may be taken as a measure of the wear of the various metals provided small differences are disregarded and attention restricted to variations of appreciable magnitude and importance. Subsequent comparisons are made in this manner with either the diameter decrease or weight change as a basis.

One of the important features shown in Fig. 3 is that gage wear was much more rapid when working in the cast iron than in the file-hard carbon steel or in the aluminum alloy, except in the case of two of the pairs of gages. These cases were that of the high-carbon high-chromium iron alloy gages, which were worn faster by the steel than by the cast iron, and that of the chromium-

²L. M. McPharlin: "The Relation of Finish to Life of Plug Gages," *American Machinist*, Vol. 65, May 12, 1927, p. 775.

³H. J. French: "Wear Testing of Metals." Paper presented before the June 1927 annual meeting, A. S. T. M., at French Lick, Ind.



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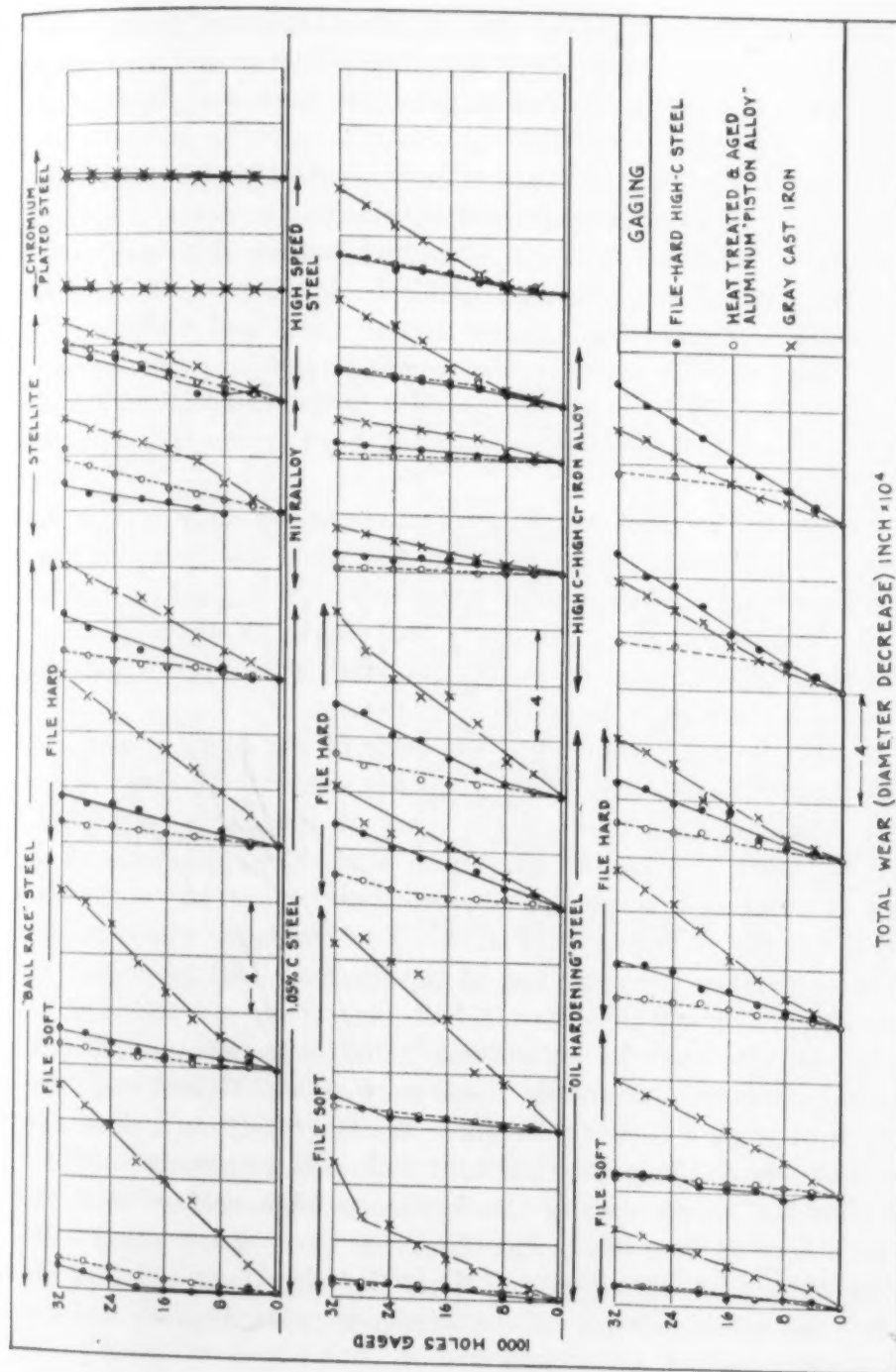


Fig. 3—Relation Between the Number of Holes Gaged and the Decrease in Diameter of the Gage in Experiments Made with the Laboratory Wear Tester.

plated gages which were worn about the same amount when used in the cast iron as in the steel.

Wear was generally greater in gages used in the file-hard

carbon steel than in gages used in the aluminum piston alloy, although this order was reversed in individual gages or in gages made from certain metals when the total wear per 32,000 holes was low.

It is of interest to note in this connection that the cast iron gaged in the described experiments was not a plain gray iron, although it contained a fairly large proportion of graphite. Its chemical composition, reported in Table I, shows it to have approximately the eutectoid proportion of combined carbon. The largest part of this exists in the form of pearlite as is shown in Fig. 1c. The presence of this pearlite probably accounts for the rapid wear of most of the gages when used in contact with this cast iron.

Probably the most important feature shown in Fig. 3 is that gages which show superior performance when used in one metal do not necessarily show similar superiority when used in another.

2. *Weight losses of the gages and rings.* A summary of the respective weight losses of gages and rings as well as their combined losses in weight is given in Fig. 4.

It will be noted that when the wear of the gages is relatively large, as in the cast iron rings, then the wear of the rings is generally relatively small; when the wear of the gages is relatively small, as when gaging the aluminum alloy, then the wear of the rings is relatively large. However, there are many exceptions to this as will be noted in Fig. 4. For example, when working in the steel rings the gage loss of the file-hard ball race steel was about twice that of the file-soft ball race steel, yet the ring loss was about the same in both cases. The chromium-plated gages constitute another exception; these showed the highest resistance to wear in gaging each of the three metals, steel, aluminum alloy and cast iron. Their small weight loss was concomitant with a low ring loss when gaging the hardened high carbon steel and no greater ring loss than was observed when using other gages in the aluminum alloy; in cast iron the ring loss was high, although the combined loss of the chromium-plated gages and cast iron rings was low.

It is, perhaps, important at this point, to note that difference in hardness as determined by the customary methods of test bears no simple relation to either the total wear or the relative

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	STELLITE
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	FILE
	FILE
	FILE
"BALL RACE" STEEL	FILE
	FILE

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wear of the two metals which are in contact. This has been pointed out repeatedly by different investigators, but is confirmed in striking manner in these tests. The aluminum alloy rings wear very rapidly in comparison with the gages, yet the cast iron rings, with a Brinell number of 179, wear much less than any of the tool steel gages with Brinell hardness over 500. Other examples can be secured from Fig. 4.

It will be noted from weight loss determinations in these experiments that low wear in one metal does not necessarily imply

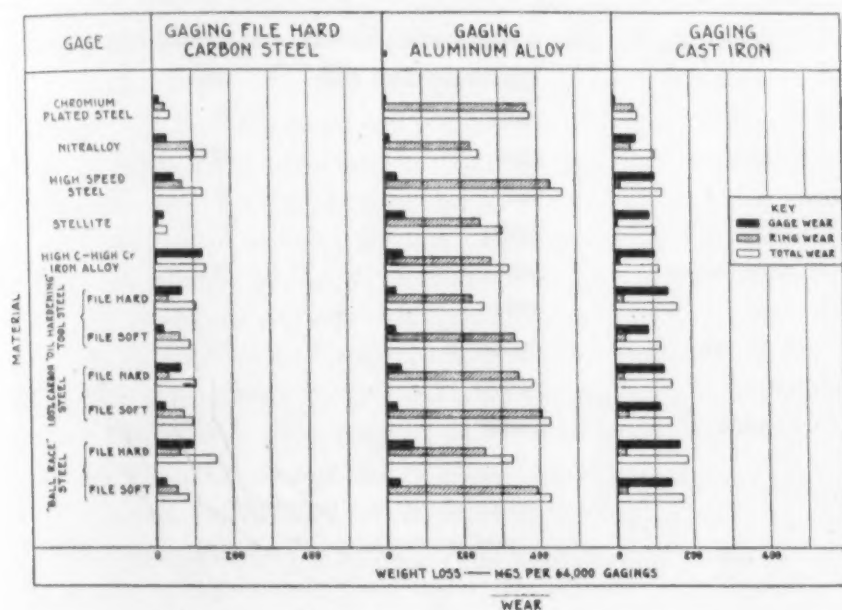


Fig. 4—Weight Loss of Gages and Rings in the Described Experiments.

corresponding high wear in the metal with which it rubs in contact. No attempt should be made to draw more detailed comparisons from Fig. 4 than are given here because the determination of weight losses was subject to certain errors which were not encountered in determining diameter changes of the gages. For example, small pieces of the Nitralloy gages were found to have broken from the threads used in mounting them in the testing machine. The recesses in the threaded holes in the gages were also difficult to clean and failure to remove all foreign matter before weighing the gages probably introduced errors into individual determinations of weight losses. For such reasons no further or more detailed comparisons seem warranted.

3. *Wear resistance of the different metals.* The wear re-

sistance of the different metals may be expressed as the number of holes gaged per one ten-thousandth of an inch diameter decrease at a point near the entering end of the gage and this may be computed from the total decreases in diameter given in Fig. 3. Results of such computations are summarized graphically in Fig. 5.

The chromium-plated gages are outstanding in their resist-

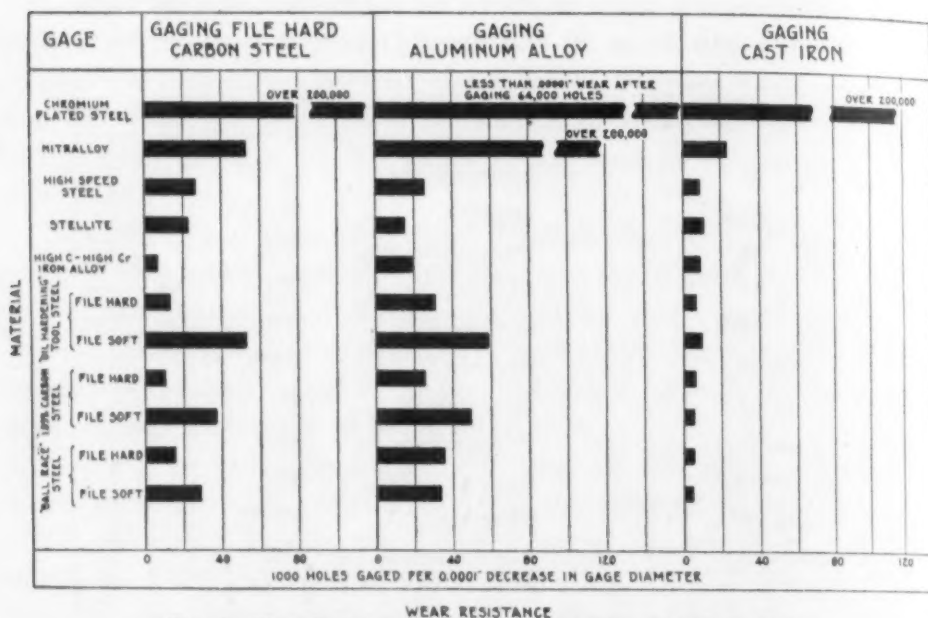


Fig. 5—Wear Resistance of the Different Gage Metals Studied.

ance to the metal-to-metal wear encountered in the steel, the aluminum alloy and the cast iron. As indicated in Fig. 5, there was less than one one-hundred-thousandth of an inch diameter decrease after gaging 32,000 holes in the aluminum piston alloy, with each of two gages, and very little change when gaging the steel or the cast iron which so quickly reduced the diameter of the gages made from most of the other metals investigated.

Second in wear resistance is the Nitralloy; its superiority was most marked when gaging the aluminum alloy but it was appreciably better than any of the other metals except chromium plate when used in cast iron. It showed excellent performance in gaging the file-hard high carbon steel, although in this case the decrease in diameter was about as great as that of the oil hardening tool steel gages in the file-soft condition.

Both the chromium-plated and the Nitralloy gages have cer-

tain disadvantages in an adhesive to crack or of the am brittle as sho holes used f these disadv gages were investigated exception, in differences

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tain disadvantages. Some difficulties were encountered in obtaining an adherent electrodeposit of chromium which did not tend to crack or flake from the base metal. Likewise the nitride case of the ammonia-treated special steel (Nitr alloy) is exceedingly brittle as shown by the breaking off of small pieces in the threaded holes used for mounting the gages in the wear tester. Despite these disadvantages, the chromium-plated gages and the Nitr alloy gages were found to be much superior to any of the other metals investigated (see Fig. 5). The remaining metals fall, with one exception, into a single group showing measurable but no radical differences in resistance to wear.

The most notable of the differences which exist is found in comparison of the file-hard and file-soft conditions of the 1.05 per cent carbon, ball race and oil hardening tool steels. In general, there is a measurable superiority in wear resistance of the file-soft gages compared to gages of the same steels in the file-hard condition. This is, perhaps, emphasized in the case of the oil hardening tool steel; the file-soft gages of this steel must be rated next to the Nitr alloy and the chromium-plated gages in wear resistance. This is shown in Table IV in which is given the position of each of the metals with respect to wear resistance in each group of tests. When the numerical values thus assigned are added the lowest total represents greatest resistance to wear while the highest totals represent relatively poor performance. It will be seen that the file-soft oil hardening tool steel gages are third in superiority of wear resistance; the remaining metals, excepting the Nitr alloy and chromium plate, show variations in performance but no striking differences. For example, the Stellite gages showed good resistance to wear when used in the cast iron, but were relatively unsatisfactory when used in the aluminum alloy.

Other comparisons may be made by reference to Fig. 5 and Table IV, in which it will be observed that as the conditions of gaging become more severe, the differences in performance of the various gage metals become generally less marked.

4. *Condition of the surfaces of the gages before and after test.* An examination was made of the condition of the surfaces of a majority of the gages before and after test to throw further light upon their wearing properties.

As would be expected, the file-hard steels showed fewer

scratches after test than the same steels in the file-soft condition. This is illustrated in Fig. 6 for the 1.05 per cent carbon and ball race steels used in the aluminum alloy and in Fig. 7 for the 1.05 per cent carbon and oil hardening tool steels used in the cast iron. In the case of the oil hardening tool steel the scratches

Table IV
Summary of the Order of Wear Resistance of Different Gage Metals in Three Sets of Tests in the Gage Wear Tester

Gage metal	Condition in which used	Position in group when gaging			Total (a)
		Steel	Al alloy	Cast iron	
Cr plate	as deposited	1	1	1	3
Nitralloy	treated	2	2	2	6
High C high Cr iron alloy	treated	11	10	5	26
High speed steel	treated	6	8	6	20
Stellite	as cast	7	11	3	21
Oil hardening tool steel	file-hard	9	7	7	23
	file-soft	3	3	4	10
Ball race steel	file-hard	8	5	10	23
	file-soft	5	6	11	22
1.05% C steel	file-hard	10	9	8	27
	file-soft	4	4	9	17

(a) The lowest total represents greatest resistance to wear.

Note: Details of the chemical compositions and heat treatments of the different gage metals are given in Tables II and III.

were not all straight but, as shown in photographs 7f and 7g, there are a number of wavy lines of unknown origin left in both the file-hard and file-soft specimens.

Gage makers and users claim that file-soft steels do not make good gages because when these have a hardness well below that of an ordinary file they are very easily marred, pick up material quite readily and do not have a satisfactory "feel". While a highly scratched surface after test is consistent with these objections it should be noted that the file-soft gages generally showed less weight loss and smaller decreases in diameter than gages made from corresponding steels in the file-hard condition. Furthermore, the degree of scratching is not necessarily an indication of suitable or unsuitable properties for gage work.

For example, the Stellite, high-carbon high-chromium iron alloy and high speed steel, gages which were found to be com-

Fig. 6—Surf. of 1.05% C Alloy. 100 x.
a. 1.05% C Pe.
b. 1.05% C Pe.
c. 1.05% C Pe.
d. Ball Race Steel.
e. Ball Race Steel.
f. Ball Race Steel.

paratively 9f, 9g and chromium- (Figs. 8b and 8c).

Due to the fact that the file-soft gages are composed of small particles of metal, they are not

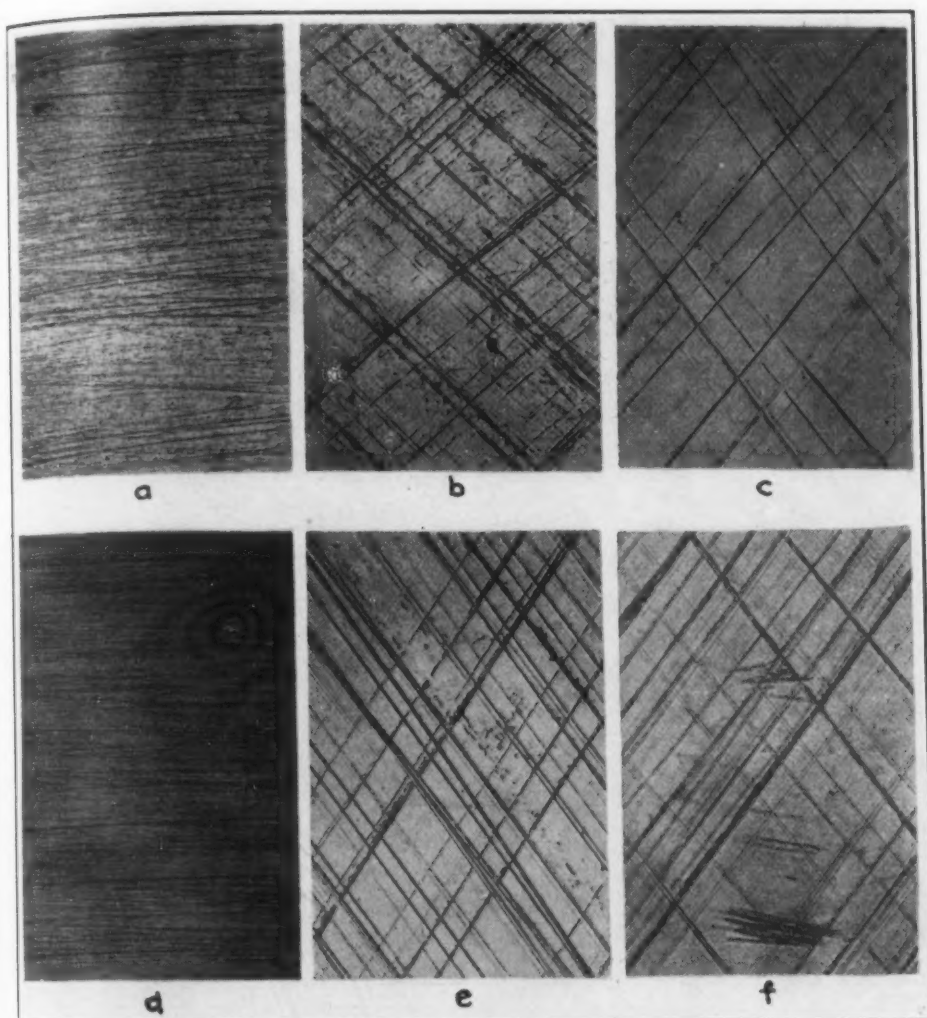


Fig. 6—Surface Condition of Some of the Gages Before and After Test in the Aluminum Alloy. 100 x.

- a. 1.05 Per Cent Carbon Steel, File-Soft, as Lapped.
- b. 1.05 Per Cent Carbon Steel, File-Soft, After Test.
- c. 1.05 Per Cent Carbon Steel, File-Hard, After Test.
- d. Ball Race Steel, File-Hard, as Lapped.
- e. Ball Race Steel, File-Soft, After Test.
- f. Ball Race Steel, File-Hard, After Test.

paratively smooth after test, as is shown in Figs. 8f, 8g, 8h and 9f, 9g and 9h, did not show as good resistance to wear as the chromium-plated gages which were found to be badly scratched (Figs. 8b and 9b).

Due to the poor adherence frequently shown by electrodeposited chromium and to its rather high degree of brittleness, small particles may readily break from the surface of the gages.

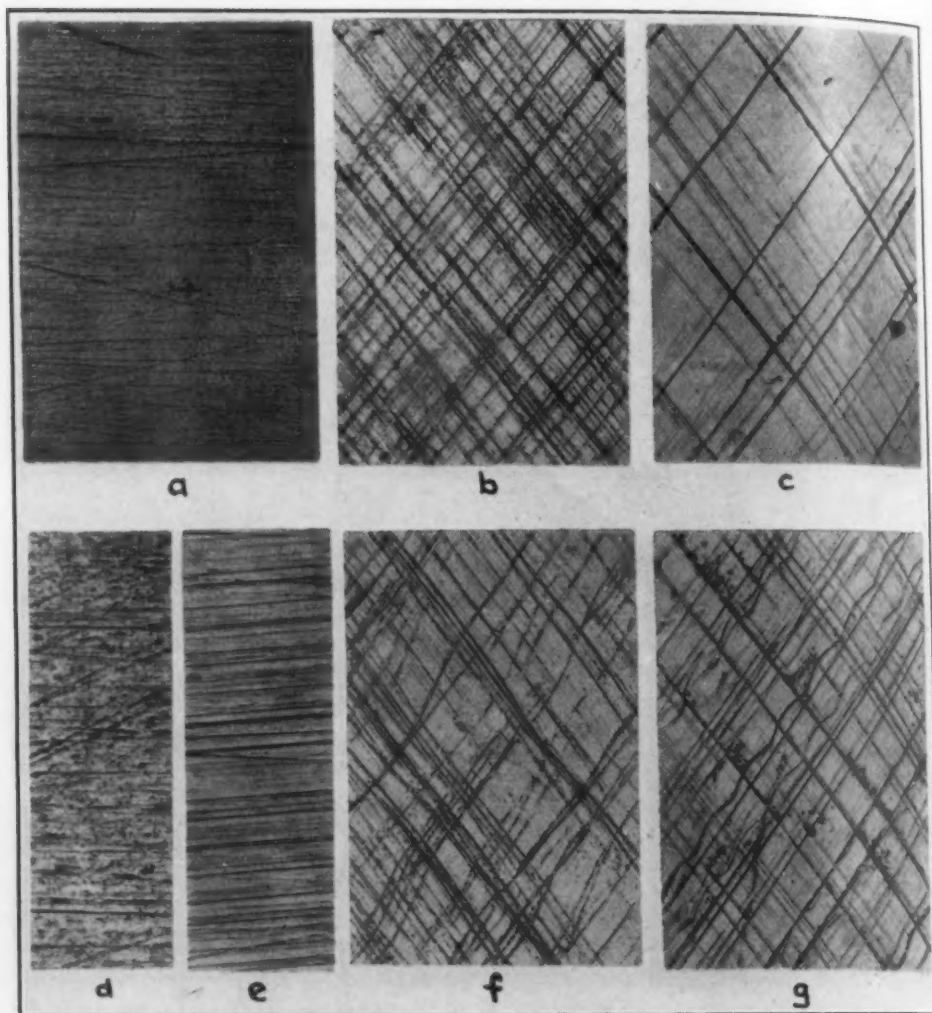


Fig. 7—Surface Condition of Some of the Gages Before and After Test in the Cast Iron.
 100 x.
 a. 1.05 Per Cent Carbon Steel, File Soft, as Lapped.
 b. 1.05 Per Cent Carbon Steel, File-Soft, After Test.
 c. 1.05 Per Cent Carbon Steel, File-Hard, After Test.
 d. Oil Hardening Steel, File-Soft, as Lapped.
 e. Oil Hardening Steel, File-Hard, as Lapped.
 f. Oil Hardening Steel, File-Soft, After Test.
 g. Oil hardening Steel, File-Hard, After Test.

Since they are extremely hard they may readily become imbedded in the somewhat softer surface of the steel or other metal in which the chromium-plated gage is used; these particles may then act as an abrasive in a lap to score the equally hard surface of the plated gage. Such a process is comparable to the observed behavior in lapping the test gages. It was found to be difficult to do any appreciable lapping with ordinary methods without

Fig. 8—
 100 x.
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 c. Nitr
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 e. Stell
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 g. High
 h. High

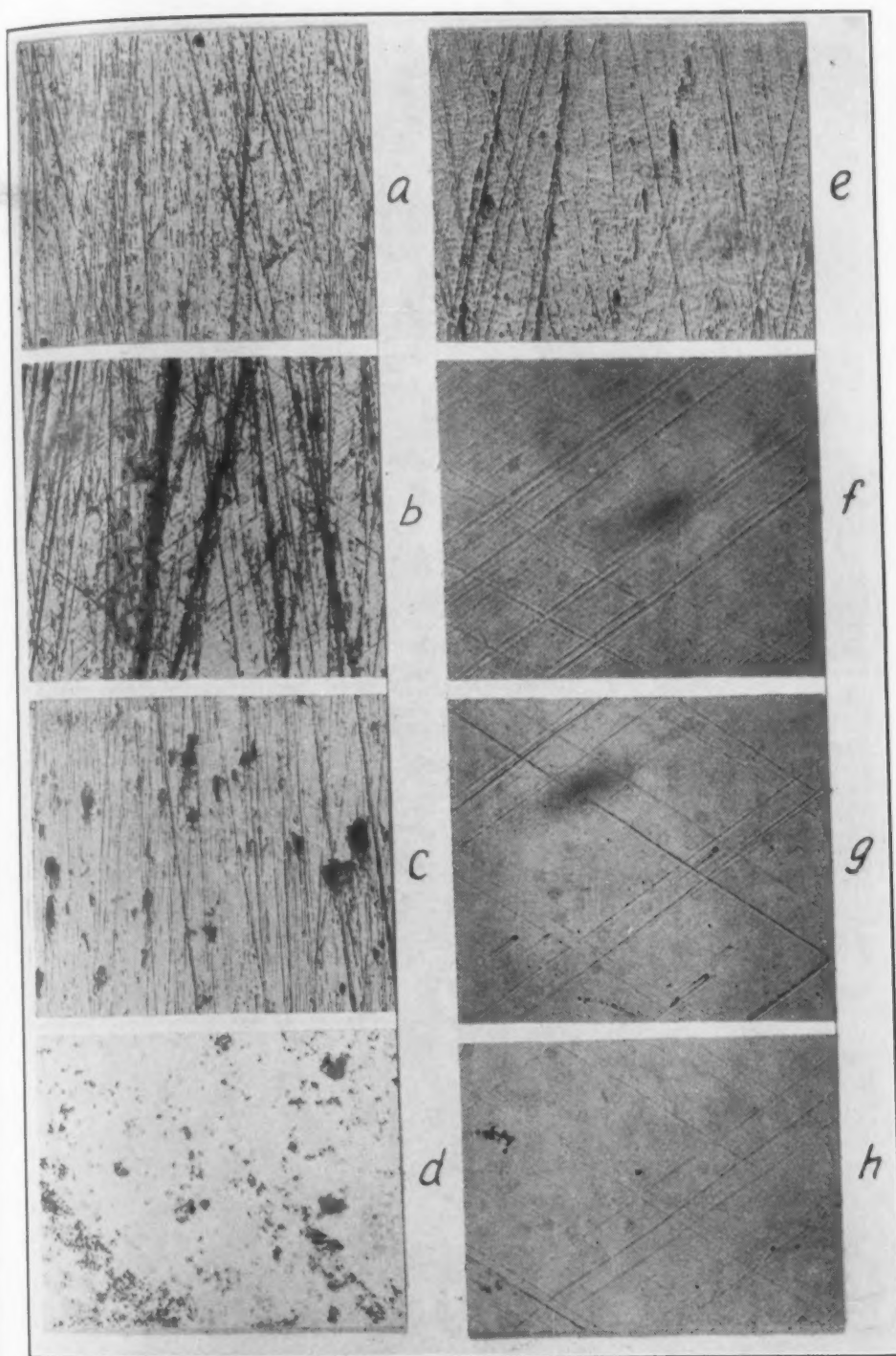


Fig. 8—Surface Condition of Some of the Gages Before and After Test in the Cast Iron.

100 x.

- a. Chromium-Plated Gage, as Lapped.
- b. Chromium-Plated Gage, After Test.
- c. Nitralloy, as Lapped.
- d. Nitralloy, After Test.
- e. Stellite, as Lapped.
- f. Stellite, After Test.
- g. High-Carbon High-Chromium Iron Alloy, After Test.
- h. High Speed Steel, After Test.

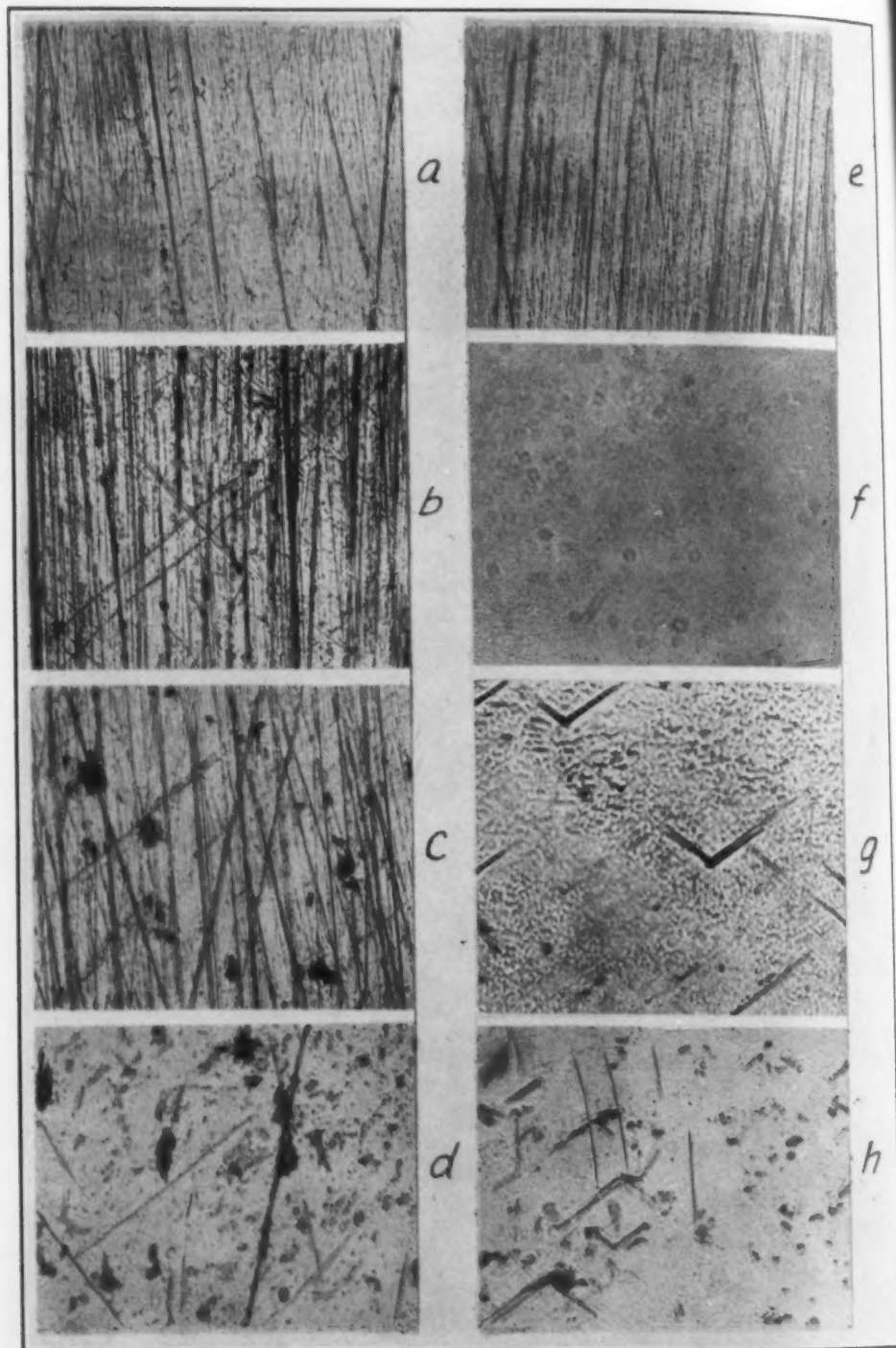


Fig. 9—Surface Condition of Some of the Gages Before and After Test in the Aluminum Alloy. 100 x.

- a. Chromium-Plated Steel, as Lapped.
- b. Chromium-Plated Steel, After Test.
- c. Nitralloy, as Lapped.
- d. Nitralloy, After Test.
- e. Stellite, as Lapped.
- f. Stellite, After Test.
- g. High-Carbon High-Chromium Iron Alloy, After Test.
- h. High Speed Steel, After Test.

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scratching the surface of the electrodeposited chromium.

With a wooden lap and light pressure an opportunity is afforded for broken hard and brittle particles of chromium to become imbedded in the wood to such a depth that they become harmless. Wood laps were employed in a number of cases in preparing the chromium-plated test gages for the described tests. Scratching occurs, not because the chromium has a poor resistance to penetration but that this metal, as ordinarily electrodeposited, is sufficiently brittle to readily break from the surface and then hard enough to scratch the plate from which it was torn.

Brittleness is a factor in the Nitralloy gages and in this case sufficiently large particles seem to have been torn from the gage surface so as to leave the pits which can readily be seen at 100 diameters in Figs. 8c, 8d, 9c and 9d. A similar effect is produced in lapping as will be evident from examination of Figs. 10c and 10d.

As already indicated in a number of places throughout this report, the brittleness of the nitride case of the chromium-aluminum steel is most marked. On the other hand, its resistance to wear of the types studied was found to be very high; in fact, its wear resistance was so high in comparison with most of the other metals studied that it would seem advantageous to sacrifice some wear resistance to permit a gain in the toughness of the case. It is understood that steels have already been produced experimentally which may be expected to show such beneficial changes when treated with ammonia.

The black areas upon two of the steels in Fig. 10 are presumed to be iron oxide and are typical of an effect which was prevalent in practically all experiments in gaging the file-hard high carbon steel. Gages used in the cast iron or in the aluminum alloy were less often observed to have similar coatings and when present these were not so heavy or well marked.

An interesting condition was found in the examination of the high-carbon high-chromium iron alloy gages after being used in the aluminum alloy rings. As previously indicated these gages showed a somewhat more rapid wear rate at the start of the tests than at subsequent intervals (See Fig. 3). This is probably due to the removal of the relatively soft matrix soon after the beginning of the test. The hard carbides, (or other hard compounds)

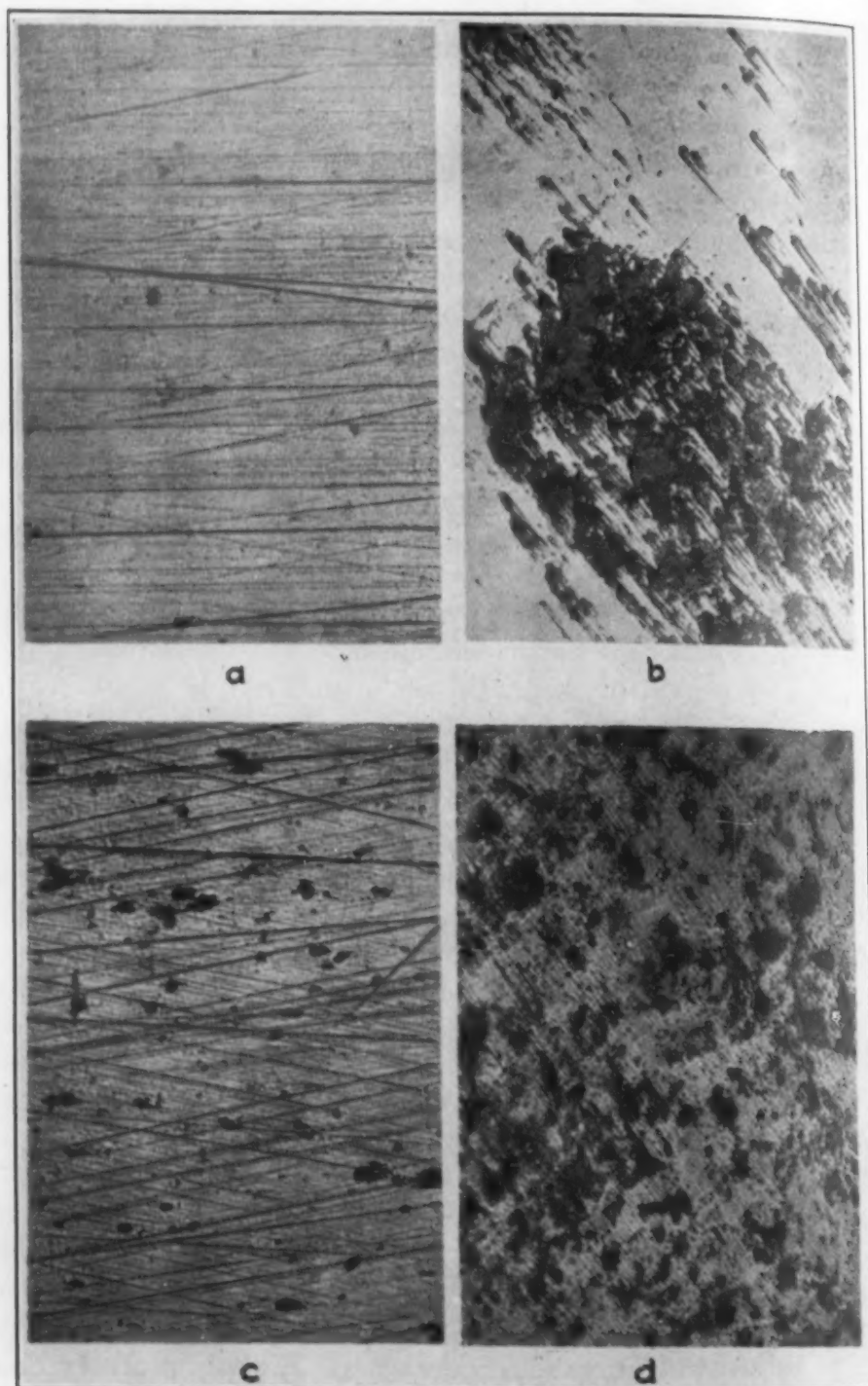


Fig. 10—Surface Condition of some of the Gages Before and After Test in File-Hard High-Carbon Steel. 100 x.

- a. High-Carbon High-Chromium Iron Alloy, as Lapped.
- b. High-Carbon High-Chromium Iron Alloy, After Test.
- c. Nitralloy, as Lapped.
- d. Nitralloy, After Test.

are then left higher resistance matrix and extend across each scratch compounds.

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are then left in relief as shown in Fig. 11b and offer a somewhat higher resistance to wear. The difference in hardness between the matrix and these compounds is shown by several scratches which extend across the specimen represented in Fig. 11b. The path of each scratch is clearly shown until it encounters one of the hard compounds. The continuity of the scratch is then broken.

In the presence of a non-metallic abrasive which has a relatively high cutting ability compared to most metals such hard compounds are less effective in reducing the wear as will be evident by comparison of Fig. 11b with the lapped surface shown in Fig. 11a and the surface of the gage subjected to an "abrasive wear test" illustrated in Fig. 11c.

5. *Effect of a non-metallic abrasive on the wear of the gages.* It was found in the preliminary tests, previously reported, that the presence of finely divided emery suspended in oil materially increased the rate of wear of the gages. Such an increase in the severity of service likewise tended to decrease the differences in wear resistance of the different gage metals.

Abrasive wear tests of the high-carbon high-chromium iron alloy and the Nitralloy gages, which were not included in the preliminary experiments, gave results consistent with these early findings as will be evident from data summarized in Table V.

The high-carbon high-chromium iron alloy receives an exceedingly favorable rating in these tests and since abrasives are frequently encountered by service gages this gives an indication of the possible basis for claims which have been made of long life for this gage metal.

The Nitralloy gages which showed very high resistance to wear in the metal-to-metal wear tests gave only mediocre performance in the abrasive wear tests.

6. *Experiments in gaging brass.* It will perhaps be worth while to record at this time certain observations made in attempting to gage wrought brass of 70 per cent copper and 30 per cent zinc. The results obtained from preliminary experiments were unsatisfactory insofar as determination of wear resistance of different gage metals was concerned. The gages did not wear but instead became coated with a copper-colored or brass-colored deposit which in some cases was of appreciable thickness. A number of attempts were made to prevent the formation of such coatings

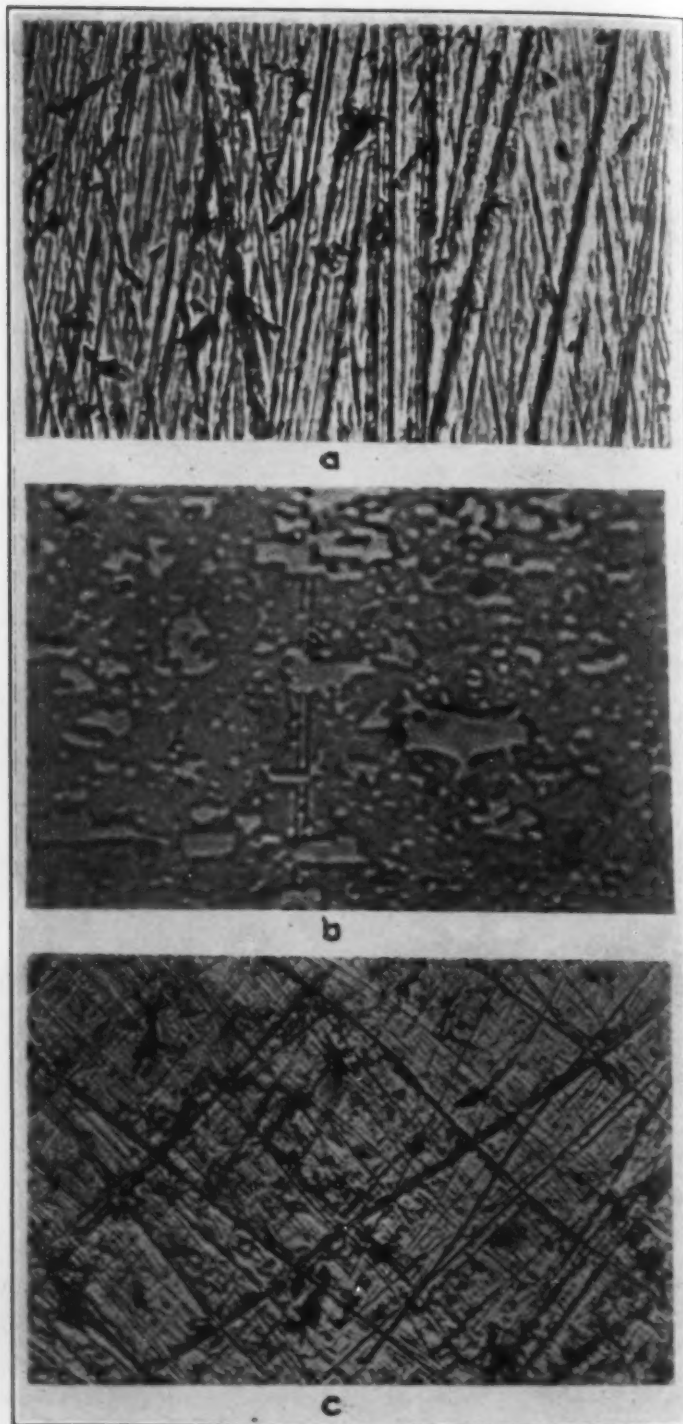


Fig. 11—Surface Condition of Some of the High-Carbon High-Chromium Iron Alloy Gages Before and After Test. 500 x.
 a. As Lapped.
 b. After Gaging 32,000 Holes in the Aluminum Alloy (Note That This is Not Etched).
 c. After Gaging 4000 Holes in File-Hard High-Carbon Steel in the Presence of Oil and 300 Mesh Emery.

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Comparisons

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 Stellite (b)
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but these were not successful and further investigation was temporarily discontinued. The potassium dichromate solution used in the metal-to-metal wear tests in gaging steel, the aluminum alloy and cast iron will dissolve the brass and under such conditions it is not surprising to find a deposit on the gage. However, coatings were likewise formed when the potassium dichromate

Table V
Comparisons of Some Gage Metals in Abrasive Wear Tests Made in the Gage Wear Tester

Gage metal	Condition in which used	Holes gaged per 0.0001 inch wear
Cr plate	as deposited	1600
Nitralloy (a)	treated	950
High C high Cr iron alloy (a)	treated	1500
Stellite (b)	as cast	2560
1.05% C steel	file-hard	825
	file-soft	1000

(a) These metals were tested about a year after the remaining metals in the group listed. Results obtained in similar tests on other gage metals are given in detail in the preliminary report referred to in footnote 1 in the text.

(b) These Stellite gages were taken from a different group than that represented by the chemical composition given in Table II. Their exact chemical composition is not known.

NOTE: Details of the conditions under which the abrasive wear tests were made are given in the report referred to in footnote 1 of the text.

Chemical compositions and heat treatments of the different gage metals are given in Tables II and III.

solution was replaced by tap water, a weak solution of sodium bicarbonate, distilled water, or alcohol of various concentrations in water or when the tests were made dry. No coatings were formed when the brass rings were replaced by bearing bronze of copper, tin and lead. It would therefore seem that the formation of the described coatings was quite largely dependent upon the brass gaged.

IV. SUMMARY AND CONCLUSIONS

The principal conclusions to be drawn from the described tests in gaging file-hard high carbon steel, a heat treated and aged aluminum alloy and a cast iron containing appreciable proportions of pearlite are included in the summary below:

1. Metals which show superior resistance to wear when used in one metal do not necessarily show superiority when used in another metal.

2. Of the numerous metals and treatments studied, chromium-plated gages showed the best resistance to wear in the metal-to-metal wear tests under consideration. The ammonia-treated chromium-aluminum steel, called Nitalloy, was second in order of wear resistance. These two metals were much superior to the remainder of the group, which showed variations but no radical differences in wearing properties. An exception was the file-soft oil hardening tool steel which was third in resistance to wear.

3. File-soft gages made from high carbon steel were generally superior in wear resistance to gages made of corresponding steels in the file-hard condition. However, the file-hard steel gages were not as badly scratched after test as the file-soft gages.

4. Gages made from Stellite, from a high-carbon high-chromium iron alloy and from hardened high speed steel were found to have fewer scratches than the gages made from file-hard or the file-soft ball race, 1.05 per cent carbon and oil hardening tool steels or chromium-plated gages. The last named consistently showed much the highest resistance to wear, but were found to be badly scratched after test. However, this was ascribed to the conditions of service which permitted particles of the brittle chromium, torn from the electrodeposit, to become imbedded in the relatively softer metal with which the chromium plate was in contact. Due to the high hardness of chromium these imbedded particles were able to score the plate. The Nitalloy gages were not scratched, but appeared to be pitted; this was ascribed to the brittleness of the nitride case which permitted particles to be torn from the surface of the gages.

5. As the conditions of gaging became more severe, either through a change in the metal gaged or by the introduction of a non-metallic abrasive, differences in wear resistance of the different gage metals became less marked. In the abrasive wear tests Stellite showed the best wear resistance while the chromium-plated gages and the high-carbon high-chromium iron alloy gages were next in line.

6. In gaging the file-hard high carbon steel (without abrasives) dark areas frequently appeared on the surfaces of the gages; these were presumed to be iron oxide. In gaging wrought brass containing about 70 per cent copper and 30 per cent zinc, copper-colored or brass-colored deposits were observed on the gages which

made it impractical to use these metals. This was true for various liquid tests, etc. Wrought lead alloy, no

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Written by J. Watervliet, N. J. Laboratories, N. J.

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Written by J. Watervliet, N. J. Watervliet, N. J.

The Nitalloy nitriding experiment has practice has especially brittleness This was acc

made it impracticable to study wear resistance of the different metals. This applied to tests made dry or in the presence of various liquids such as water, alcohol, sodium bicarbonate solutions, etc. When this brass was replaced by a cast copper-tin-lead alloy, no such coatings were observed.

ACKNOWLEDGMENTS

The authors are indebted to the Ludlum Steel Company, Watervliet, N. Y., for supplying the chromium-aluminum steel and treating this after being made up into the gages referred to in the text under the name Nitalloy; to the Haynes Stellite Company, Kokomo, Ind., for supplying the Stellite castings. Acknowledgment is made to R. F. Staubly, Jr., laboratory apprentice, for making the majority of the wear tests, to D. R. Miller of the Division of Weights and Measures, under whose supervision many of the test gages were prepared and to W. Blum of the Chemistry Division under whose supervision the chromium was electrodeposited.

DISCUSSION

Written Discussion: By B. E. Field, Union Carbon and Carbide Research Laboratories, Long Island City.

The authors are to be congratulated upon this contribution to our knowledge of the wear resistance of metals. It represents a large amount of work of a kind which is tedious to carry out but which requires the utmost care if the results are to be worth anything. There is one point to which I would like to draw attention in connection with the abrasive wear tests which are summarized in Table 5. In most gaging operations carried out in the shop some abrasive is present and this accounts for the fact that when gages of steel and Stellite are tested in actual use the Stellite gages show in most instances a very much longer life. This is in agreement with the results which the authors have given in Table 5 and indicates that for the selection of a gage material for actual working conditions more reliance should be placed upon the comparisons given in Table 5 than those given in Table 4 where no abrasive was present.

Written Discussion: By H. A. De Fries, Ludlum Steel Company, Watervliet, N. Y.

The Nitalloy gages mentioned in this paper represent one of the earliest nitriding experiments carried on by the Ludlum Steel Co. Since then the practice has been changed considerably and the drawbacks mentioned, especially brittleness of the nitrided case, has been overcome to a very great extent. This was accomplished by various means which will be enumerated below:

1. Additional alloying elements were incorporated in the steels, which have a tempering effect on the case and some of the extreme hardness was sacrificed towards more ductility.

2. As seen from the structure in Fig. 2, the upper layers show an excess of nitrides, which have separated out of solution as needles. It was proven that such a structure always possesses extreme brittleness. In order to keep the nitrides in solution, the nitriding temperature was lowered from 950 to 875 degrees Fahr.

3. The effect of the hydrogen present from the disassociation of the ammonia was also studied and it was found that a high degree of free

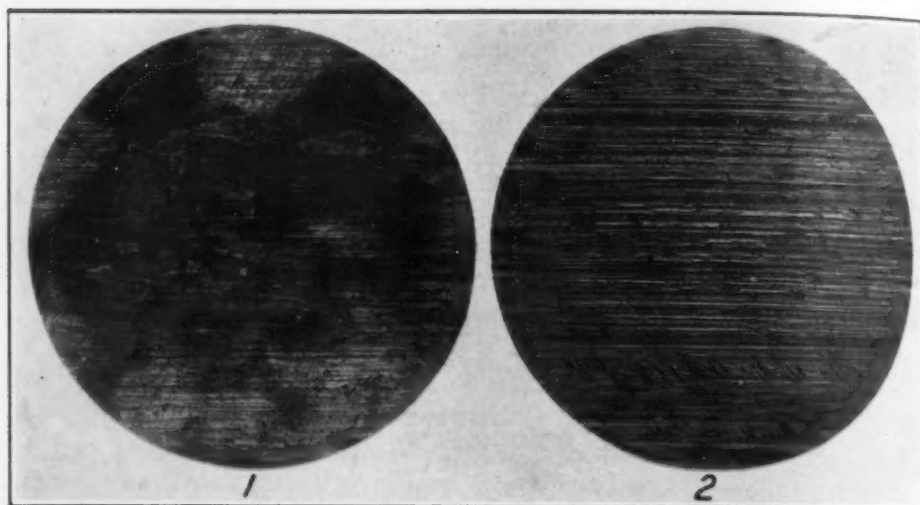


Fig. 1—Photomicrograph of a Nitrided Disk with the Surface of the Case Roughly Polished. Fig. 2—Photomicrograph of the Same Nitrided Disk with 1/1000 inch of the Case Removed by Rough Grinding. Magnification 100 x. Herbert Hardness Numbers were 890 and 970 Respectively.

hydrogen will produce a decarbonization of the upper case with attending swelling and sponginess. For this reason, the disassociation of the ammonia was decreased from 30 per cent to 10-15 per cent maximum. The latter ratio will only produce sponginess in the very uppermost film, but will not affect the case proper.

4. To get an accurate picture of the nitrided case and its relative hardness from surface to junction with care, a perfect cylinder was nitrided and then ground to a taper. Herbert hardness readings were then taken at certain intervals which showed that the hardest part of the case is located about 0.0005 to 0.001 of an inch below the surface. This experiment also proved that the case depth with 90 hours treatment averages 0.031-inch. One half of this is visible, whereas the nitrogen concentration in the bottom half is so low that it has produced no marked change in the structure. To further substantiate this statement, a disk was nitrided—one side of which was roughly polished, whereas on the other side 1/1000-inch was removed by rough grinding. Fig. 1 of this discussion shows the polished side; Fig. 2 of this discussion the side

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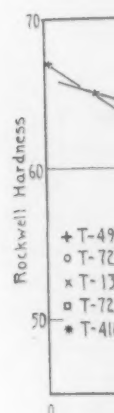
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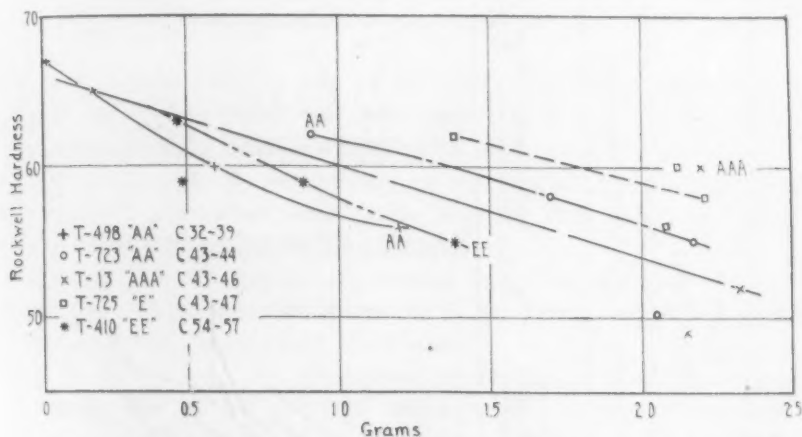
with 1/1000-inch of the case removed. The relative Herbert numbers were 890 for Fig. 1 against 970 for Fig. 2.

The above considerations lead us to the conclusion that Nitralloy gages should be nitrided with about 0.002-inch oversize diameter at about 875 degrees Fahr. and with a disassociation of ammonia not exceeding 15 per cent. After such nitriding, the gages are to be ground and lapped to size.

On account of the extreme hardness of case, Nitralloy gages always will have surfaces which are easier chipped than hardened alloy or tool steel gages, and, therefore, have to be handled more carefully.

Written Discussion: By J. L. McCloud, Ford Motor Company, Dearborn, Michigan.

This new paper by French and Herschman on wear of plug gages gives new information to add to that given in their last paper on the same subject.



Curves Showing the Wear of Tool Steel as Indicated by Loss in Weight in Grams on 1 1/4-Inch Roller After 1,000,000 Revolutions in the Amsler Wear Tester.

At the time of the presentation of this first paper we had started an investigation of just the same thing. We carried on our work however, on an Amsler machine. This machine as shown in a diagram in the first paper uses two rollers in contact, independently driven. The upper roller is driven at a speed 10 per cent greater than the lower and is caused to slide to and fro thus preventing the formation of any circumferential grooves. In our work we made the upper roller two times the diameter of the lower. The sizes were 2 1/2 and 1 1/4 inches in diameter respectively and 0.394 inch thick. This gives an even greater sliding action between the surface in contact.

The machine is equipped to be able to vary the pressure between the rollers but we have found that with this type of a setup more easily reproducible results are obtained by using only the weight of the head which is about 20 kilograms.

The test runs were all 1,000,000 revolutions of the lower spindle. Measurements of the diameters of the rollers was made on a Newell measuring machine indicating 0.00001 inch and weight losses were taken on an analytical balance to 0.0001 grams. The diameter measurements were difficult to check in the

Table I
Wear Tests
Each Pair of Rollers Run 1,000,000 Revolutions
Load 20 Kilograms. No Lubricant Used

2.500 Diameter Rollers Roller No.	2.500 Diameter Rollers "T" No.	Type Steel	(Roller on Upper Spindle)				Roller No.	1.250 Diameter Rollers Temper	Type Steel	Rockwell Hardness	(Roller on Lower Spindle)			
			Rockwell Hardness	Grams Loss in Weight	Loss in Diameter, Inches	Loss in Diameter, Inches					Rockwell Hardness	Grams Loss in Weight	Loss in Diameter, Inches	Loss in Diameter, Inches
17	498	AA	C 38 39	.0519	.00028	.00011	29	300° F.	T. S.	C 65 67	.0170	.00011	.00011	.00011
18			C 32 34	.2292	.00128	.01636	23	400° F.		C 59 60	1.6496	.01636	.01636	.01636
19			C 37 38	1.9293	.00980	.00572	25	450° F.		C 60 60	.5956	.00572	.00572	.00572
20			C 37 38	1.1057	.00504	.01123	21	500° F.		C 55 56	1.1958	.01123	.01123	.01123
1	723	AA	C 43 44	1.5799	.00718	.00836	30	400° F.	T. S.	C 61 62	.9221	.00836	.00836	.00836
2			C 43 44	.3382	.00136	.01695	27	450° F.		C 56 58	1.7062	.01695	.01695	.01695
3			C 43 44	.4737	.00106	.02166	22	500° F.		C 55 55	2.1759	.02166	.02166	.02166
4			C 43 44	.1610	.00030	.02066	24	550° F.		C 48 50	2.0588	.02066	.02066	.02066
5	13	AAA	C 44 44	.0613	.00016	.00185	31	300° F.	T. S.	C 64 65	.1821	.00185	.00185	.00185
6			C 43 44	.5393	.00182	.01240	35	400° F.		C 60 60	2.1941	.01240	.01240	.01240
7			C 44 45	1.748	.00057	.02149	28	450° F.		C 48 49	2.1371	.02149	.02149	.02149
8			C 45 46	.3284	.00105	.02372	26	550° F.		C 51 52	2.3334	.02372	.02372	.02372
13	725	E	C 44 45	.7605	.00316	.01992	36	300° F.	T. S.	C 60 60	2.1223	.01992	.01992	.01992
14			C 45 46	.3820	.00132	.02075	37	400° F.		C 55 56	2.0808	.02075	.02075	.02075
15			C 43 44	1.2180	.00388	.01335	33	500° F.		C 60 62	1.3900	.01335	.01335	.01335
16			C 45 47	.1013	.00020	.02273	39	550° F.		C 57 58	2.1923	.02273	.02273	.02273
9	410	EE	C 55 57	.0899	.00017	.00467	38	300° F.	T. S.	C 63 63	.4798	.00467	.00467	.00467
10			C 54 56	.0241	.00014	.00894	32	450° F.		C 58 59	.8665	.00894	.00894	.00894
11			C 56 57	.0357	.00018	.00493	34	500° F.		C 57 59	.4932	.00493	.00493	.00493
12			C 55 57	.0538	.00012	.01930	40	550° F.		C 53 55	1.8761	.01930	.01930	.01930

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cases of considerable wear as the rollers were not always strictly round at the end of a test.

The question at issue was, were there parts that we were gaging where a file-soft (used in same way as French and Herschman) gage would be indicated to be better than one file-hard. While admittedly it is a difficult thing to describe in terms of some hardness number, we find that for the type of gage steel we were using, a 1.00 per cent carbon tool steel, the line between these hardness conditions is to be drawn at about 62C Rockwell.

The steels acting as parts to be gaged were AA, a water quenching 0.30 per cent carbon-chromium steel, AAA a 0.35 per cent carbon-chromium oil-quenched steel, E a 0.32 per cent carbon 0.80 per cent manganese water-quenched—all tempered to the hardness as given in the table and EE a water-quenched 0.38 per cent carbon 0.80 per cent manganese steel and oil-tempered to the hardness given. These represented conditions in the "T" parts as indicated.

The table shows that for any of the conditions investigated less wear on the gaging (tool steel) roller was experienced the harder it was. It shows as well that the highest Rockwell number gage gave the best result.

On the curve will be noted some points that do not fall on these lines but the general conclusions seem to be justified that for these conditions a gage left in its hardest condition is best.

This is as well the generally admitted belief in our plants that file-hard gages are best. Also this was stated by L. A. Danse and A. H. d'Arcambal and others as being experienced elsewhere.

A. H. D'ARCAMBAL: Mr. Chairman, we are again indebted to our friends at the Bureau for another excellent paper on this all-important subject. We believe that the high carbon, high chromium alloy gages would have shown up much better in the abrasive wear test and also the metal to metal wear test if they had been hardened so as to have shown a Rockwell of C-64 to C-65. In other words, Mr. French quenched these gages from a temperature 100 to 150 degrees higher than is the usual practice, resulting in considerable retained austenite, the tempering temperature not being sufficiently high to change this to martensite, these gages therefore showing a low Rockwell reading C-55, I believe. We have found by actual service tests on gages made from this high carbon, high chromium material, hardened to a Rockwell of C-64 to C-65 and, of course, file-hard, that these gages gave well over double the life of ordinary plain carbon tool steel gages, and in the only case tested against Stellite, gave considerable more wear than the Stellite gages.

I might add that the gage manufacturers are continuing to turn out file-hard gages, due to the fact that the customer will not accept gages that can be filed. It is true that some of the gage manufacturers are tempering their gages slightly higher than others, resulting in a gage that can just be touched with a flat Nicholson file and showing a Rockwell of about C-63, but we have found it the best practice to temper our gages at a low temperature, resulting in a file-hard gage with a Rockwell of C-65-66.

In a discussion a year ago, the speaker brought out the point that one cannot obtain as satisfactory a finish on a soft gage as is possible from a

file-hard gage, this, gentlemen, being a very important factor in gage life. The life of cylindrical plug gages is dependent to a very great extent on the finish, as brought out by Mr. MacFarland of the Studebaker Corporation in a paper some time ago.

The so-called "feel" factor is also very important. One cannot obtain the proper "feel" from the gages that are not file-hard.

I had the pleasure of looking over this apparatus of Mr. French's at the Bureau a few months ago and believe it is the best machine that has ever been brought out for wear tests. On the other hand, it does not exactly duplicate conditions in service. I mean that in a plant gaging, we will say, ground holes, the plug enters a different sample each time, whereas in the case of the wear test machine the same ring must necessarily be used throughout the test.

O. Z. KLOPSCH: This paper presented by Mr. French is of great value and interest to all of us, and a lot of us may wish to use this data in applications to other types of wear. In the past year some of the drawn tube people, copper tube and steel tube, have carried out some experiments using chromium plated plugs. It might be of interest to quote a few of their results.

Apparently, in drawing copper tubes, which are not very hard and which have far less pressure than in drawing steel tubes, the chromium plating gives wear which runs, I have heard values given from five to fourteen times in excess of what they formerly obtained in hardened carbon steel. Now, when these chromium plated plugs were used on the first draws, which are very heavy, and, consequently, with high pressures, they may not stand up. In other words, the plating may break down, the pressure being too great for this relatively brittle material; incidently, the plating was done on hardened steel, so that it had a good support.

In the drawing of steel tubes, however, where the pressures are necessarily greater than would be obtained on any type of draw with the copper tubing, they did not stand up at all, in fact, one or two passes were sufficient to break down the chromium plating. I mention this merely as a warning so that when we try to apply this type of wear resistance to other problems, that we will also consider the pressure being used.

A. L. DAVIS: May I ask the last speaker what was the manner in which the chromium plate broke down. That is, was it a question of the plate peeling off or what?

O. Z. KLOPSCH: The plate actually cracked and peeled off.

A. E. FLOWERS: I would like to ask Mr. French whether any tests have been made with chromium plate against chromium plate, and whether we might conclude that the results of wear tests of chromium plate against hardened steel would be at all similar to chromium plate against chromium plate.

I also want to call attention to the fact that in operating some of our small separators, the rotating element runs with a step bearing consisting of what we call two points, in a vertical position. It is a vertical spindle machine, running at quite high speed, and lubricated. In making some tests recently on the points used for this purpose, we were rather surprised to find that the hardened tool steel that was file-soft gave much better wearing re-

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sults than that which was file hard. This was contrary to the general opinion on the subject of wear points and contrary to the inspection practice which has been to reject points that are file-soft. I would like, therefore, to ask the question as to whether any other people have observed similar wear results between file-hard and file-soft tool steel after quenching for hardening for cutting tools.

W. L. LEVEDAHL: Mr. Chairman: It was just a year ago at this time, immediately after the Chicago Convention, that Mr. French was asked to come out to our plant and examine our gaging conditions. He did so and the exchange of information and our plan of working and experimenting along the lines brought out in his paper, has in the past year given us very profitable results.

For several years prior to this we had been experimenting with various steels and heat treatments in an effort to produce a plug gage having high wear resistance. We concentrated on a case-hardened plug, file-hard. The results obtained were gratifying, these plug gages having a life of 90 per cent compared to plug gages purchased from a firm of high reputation, and which we rated 100 per cent, for comparative figures.

Following Mr. French's visit we have experimented with plain carbon steel, water-hardened, and oil-hardened steel, and due to better practice both as to heat treatment, finish, and gaging operation, we have shown increased life for both types. However, the oil-hardening type, soft to the file, has given the best results in number of holes gaged. Our figures show an increase of 70 per cent holes gaged over the case-hardened plug gage mentioned.

It should be stated that these gages were used on case-hardened, ground and lapped piston bores of pneumatic hammer barrels, and in all the tests were used by the same operator so as to assure us of conditions as uniform as possible.

Our records of experiments carried out during the year brought out the fact that some operators were wearing out the gages in one-half or one-quarter of the high record set by other operators, and these percentages showed the same, no matter what type of steel was used. Our gage inspector therefore states that "In addition to producing a high grade gage we will have to produce operators who will handle gages in the right way."

There are, of course, many variables which enter into tests of this kind, but we feel that the experimental work and research started as a result of the paper last year has been a great help to us and we will continue to work along those lines and check our results.

W. J. MERTEN: Mr. chairman while at Washington, a suggestion was made by Mr. Palmer of the Carpenter Steel Company in a discussion of the paper on "the wear resistance of cutting edges of steels for cutting high silicon sheets," advocating carburizing of high speed steel at 1900 degrees Fahr. to obtain extreme hardness of edge. We carried out this suggestion and have had remarkable results, probably the suggestion should receive some consideration also in regard to plug gages made of high speed steels, somewhat supplementing and confirming Mr. d'Arcambal's suggestion on high speed steel gages.

E. J. P. FISHER: Mr. Chairman, I would like to ask Mr. French if either soft or hard plug gages can be chromium plated, and with the same results.

H. J. FRENCH: I am very much gratified, and I know if Mr. Herschman were here, he would be too, at the amount of discussion that has been brought out by this paper.

In answer to Mr. Fisher's question, both hard and soft steels can be chromium plated but it is not ordinarily considered desirable to plate soft steels with chromium. Chromium is exceedingly hard, and likewise brittle, and the support offered to the chromium plate by a hard backing is often very desirable and sometimes the balancing feature in determining whether or not good service will be obtained. It is possible that for certain types of service there is little or no difference whether the deposit is placed on something soft or something hard, but as a general rule, I would favor a moderately hard base if there were no very definite reason why it was necessary to use a very soft one.

I was glad to hear what Mr. Flowers had to say regarding wear of file-soft versus file-hard steels. That question is still controversial and much of the discussion seems to have revolved about the question as to whether a steel in the hardest possible condition, as we now measure hardness, better resists wear than the same steel in a file-soft condition. Mr. McCloud has given some very interesting results which throw further light on that question, and I think that it might be worth while to point out that his results, in which he found a better resistance to wear the harder the steels, are not necessarily inconsistent with the results which we have obtained, in which we found that the file-soft steels generally had a better wear resistance than the same steels file-hard.

Now, there are some very definite reasons for this. Mr. McCloud used an Amsler Wear Tester similar to one which has been in use for several years in the laboratories of the Bureau of Standards and with which we have acquired considerable experience. The Amsler tester, used by Mr. McCloud, provides for the simultaneous rotation in contact, at different speeds of two disks. With the head pressure of about 20 kilograms and the small contact area existing between the 2 disks used by Mr. McCloud, the unit contact pressures, computed by Hertz' formulae, will be in the neighborhood of 45,000 pounds per square inch. The contact pressures in our gage wear tester, used in the tests which I described this morning, were in the neighborhood of 25 pounds per square inch. With such a wide difference in contact pressures it is not unreasonable to expect differences in the ratings of different metals.

In other words the conditions of Mr. McCloud's experiments were very different from those encountered in our gage tests. We originally considered the use of the Amsler Wear Tester for gages but due to the difficulty of reducing the contact pressures, to values somewhere near those which might be expected in practical gage service, we designed and used the special gage tester described.

Of course, the contact pressure can be reduced by replacing one of the rotating specimens by a stationary specimen but under such conditions rapid

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heating will occur at the contact surfaces and the tests really are being made at elevated temperatures under variable conditions. I feel that Mr. McCloud's results are not inconsistent with those which we have obtained in our gage tester, but I do think that a full explanation is necessary in attempting to interpret and correlate the two sets of experiments.

I do not want to be misunderstood for I am not criticizing the use of the Amsler machine. We have used it widely for purposes other than gage steels with interesting results.

In reply to Mr. d'Arcambal, I suggest that he look through our report carefully to find anywhere the recommendation that file-soft steels be used to make gages. We point out that in many cases in the metal-to-metal wear tests, file-soft steels showed better wear resistance than the same steels in the file-hard condition but we also point out that the former scratch more easily and have other disadvantages. The application of any of these data must rest with individuals in the industry, who must balance the factor of wear against other items for each application under consideration.

However, it seems significant that different manufacturers are not in agreement either as to the steel which best meets general requirements for plug gages or the particular treatments or hardnesses which best meet the needs of the industry, and we have simply attempted to point out variations in important properties.

With respect to Mr. DeFries comments on the Nitralloy gages, I would like to put on record several facts which were not included in the original report. The gages grew in heat treatment and on that account, it was necessary for us subsequently to lap or grind them. It is probable that the wearing surface was in the zone of highest hardness, just under the skin, and so emphasized brittleness. Additional tests have since been made with Cr-Ni-Al steels treated in ammonia. The white band shown in Fig. 2 of the paper was absent and the Cr-Ni-Al steel gages were not so brittle nor did they show as good wearing properties as the Cr-Ni steel gages referred to in the report.

In reply to Mr. Flowers, we have not completed tests in which chromium plate was in contact with chromium plate but expect to have such data in the near future.

We are pleased to have Mr. Merten's suggestions on carburized high speed steels and if opportunity is offered will follow this up. It is also gratifying to note the success of Mr. Levedahl's experiments which were prompted by our previous report.

We hope that those of you who are making wear tests, will bring the results to light for one of the difficult problems ahead is to trap the important variables of wear testing and to determine their importance for different types of service. Reliable data added to existing knowledge will help materially to give a correct picture of the whole field.

FORGING MACHINE DIE DESIGN FOR DEEP PIERCING

BY E. R. FROST

Abstract

This paper describes the method and die design for producing upset machine forgings having deep holes pierced through them. The procedure to be followed in the design of the dies and piercers, as well as the pitfalls to be avoided, are described. The kind of material that can be forged; the working temperatures, and the kind of steel and treatment for piercer tools are covered. There are numerous illustrations showing the various applications of this method to a wide variety of forgings.

TO the best of the author's knowledge, the idea of progressive deep piercing has only recently been put into practice on the forging machine. Previous attempts along this line failed on account of off-center holes and breakage of the punches, caused by inability to maintain the necessary alignment of the tools. However, the advent of the stiffer type of forging machine, with its improved means for maintaining alignment of the gripping dies, and with its long "piloted" heading slide, led to further experiments along this line. Present day alignment was found to insure concentricity of the punches with the impressions in the gripping dies; and the trouble from broken punches has been practically eliminated by this means. As a result, experience indicates that deep piercing of forgings can now be attempted with every assurance of success.

It has been customary for some time to form the cavity of socket wrenches on the forging machine; and it was soon found that the life of the punch was from 10,000 to 20,000 forgings before wear developed exceeding ten thousandths of an inch across the flats of the punch. This excellent life was one of the early indications that satisfactory tool life might be expected on piercing work.

An examination of the die design for this socket wrench forg-

A paper presented before the ninth annual convention of the Society held in Detroit, September 19 to 23, 1927. The author, E. R. Frost is president of the National Machinery Company, Tiffin, Ohio. The manuscript was received August 15, 1927.

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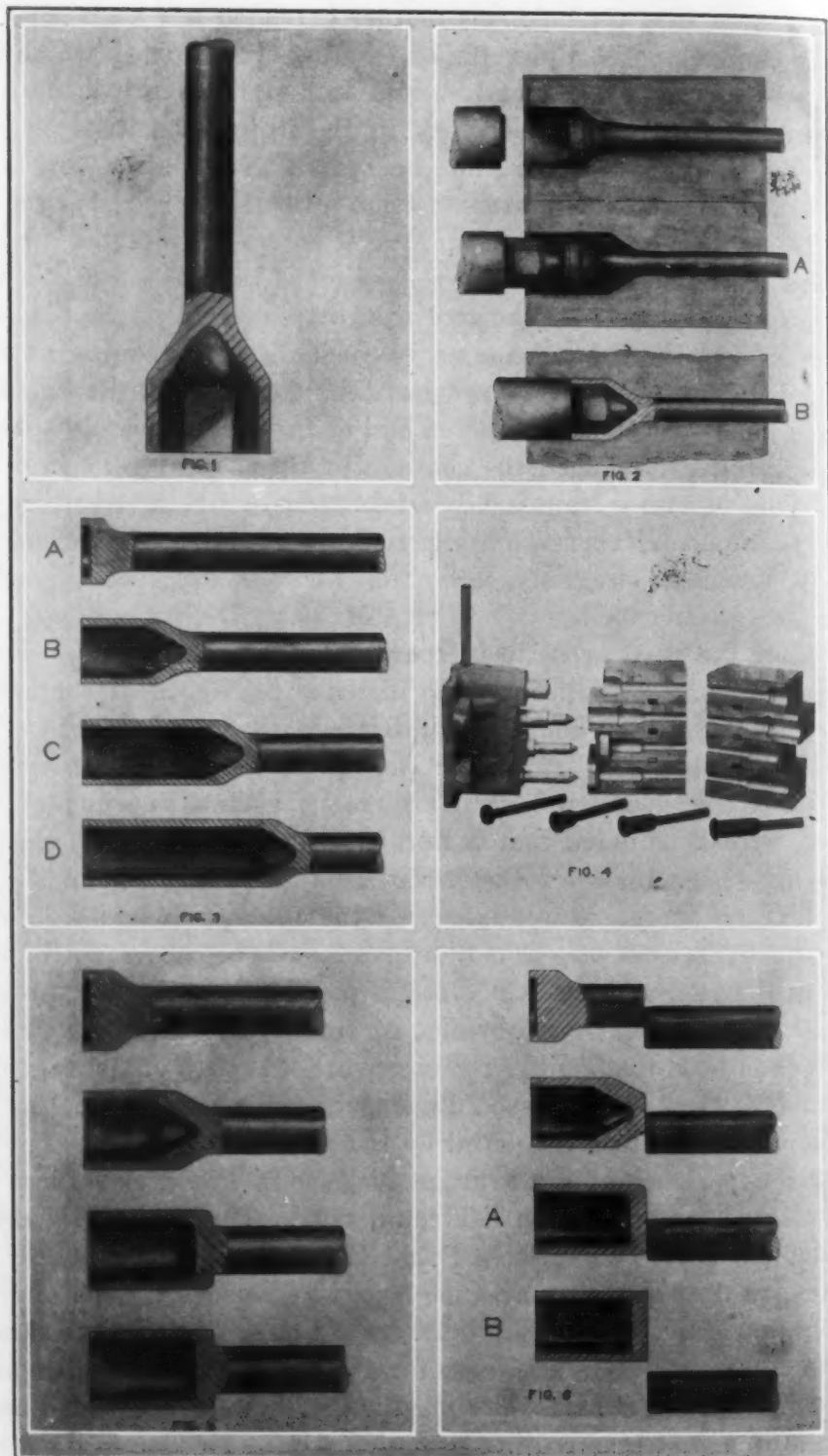
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ing indicated that the hole was neither extruded nor punched, but was developed by just a piercing or forming operation, in which the stock was merely opened and shaped into position in the die impression—the length of the stock in the impression, both before and after the piercing operation, being exactly the same.

Fig. 1 represents a cross section of such a socket wrench. Fig. 2A shows the form of the upset as it enters the piercing die impression, and Fig. 2B shows the relocation of this same stock in the impression after the piercing tool has completed its stroke. It will be noted that there has been no extrusion or lengthening of the upset portion, and that no stock has been forced back through the gripping impression. The tapered end of the piercer merely spread the stock until it reached the confines of the gripping die impression. This, of course, causes only a minimum of strain to be thrown upon the piercer, corresponding to that required to forge the material—which, obviously, accounts for the long life secured from such piecing tools.

When the need arose to pierce deeper holes, we asked, “Why not repeat this same operation to increase the depth of the hole? And, if the operation could be duplicated, why could it not be repeated several times, if greater depths of hole were desired?” This led to the idea of progressive piercing, such as represented by Fig. 3. It will be noted that A and B of Fig. 3 correspond closely to the die design for the socket wrench shown in Fig. 2. In Fig. 3 C and D are merely duplications of the first piercing operation. It is evident in each case that there is no endwise movement of the stock in forging, and that the stock is merely laid out into the impression in the die. It is obvious, of course, that the area of the bar stock must correspond to the cross-sectional area of the forging, and that the free space in the die impression must be sufficient to accommodate the stock displaced by the piercer.

The experience of the average forge man would cause him to say that satisfactory punch life could not be expected. However, the fact must not be overlooked that the problems encountered in progressive deep piercing are not nearly so serious as in the case of deep punching. The tapered piercer is not subjected to the same strains that occur upon a punch, for the piercer merely splits and then expands the hot stock, causing the piercer to be subjected only to the ordinary strains required for upsetting. In piercing a forg-



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ing, of course, the tip of the piercer must actually shear and sever the stock, but the area being so severed is extremely small compared with that in a regular punching operation. A punch must sever an area corresponding to its circumference multiplied by the depth, hence, to punch a 1-inch diameter round hole, with a square end punch, through 1 inch of stock heated to a temperature of 2000 degrees Fahr., and figuring 4800 pounds per square inch as the hot strength of the steel, would cause a pressure upon the punch of 15,000 pounds. And any increase in the depth would increase the pressure in direct proportion. However, such pressures are not encountered in the method described in this paper, for it must be remembered that these piercing operations are on bars of such size that they can be easily deflected or spread by the tapered end of the piercer. Consequently, to pierce a 1-inch diameter round hole, at the above temperature, with a piercer having a tapered end, requires a pressure upon the piercer of only 3800 pounds; and there is no material increase in this pressure regardless of the depth of the hole. The fact that the pressures encountered are much less than in punching, and that each piercer is subjected to only a limited amount of heating, is what accounts for the satisfactory life which such piercers show on this class of work.

Fig. 4 is a photograph of the die for solid drag link forgings used on automobiles; and experience of more than a year shows that the life of the piercers is from 8,000 to 12,000 forgings per redressing.

The importance of this method of progressive piercing becomes apparent when the many applications to various types of forgings are considered. Should it be desired to form a hole with practically a square bottom, additional squaring operations, as indicated in Fig. 5, could be provided. If it is desired that the forging be severed from the bar, it could, of course, be hot-sawed, or sheared off in the die with a side shear. Hot sawing has many disadvantages, and side shearing in the die has a tendency to drag the hot stock, causing a badly rounded corner on the end of the forging. However, a design of die has recently been developed in which the forging is partially sheared from the bar, with the shear serving as a backing in the die, against which the stock is forced by the piercing tool, thereby squaring the end, as indicated in Fig. 6A. The fact that the forging is still attached to the bar enables it to be

transferred to another impression in the die, in which the shearing operation can be completed, as shown in Fig. 6B. Fig. 7 shows such a die design in which the end of the forging is squared against the shear by the last piercing tool, and in which the last operation severs the forging from the bar.

Probably one of the most important applications of this idea of deep piercing is the making of forgings sheared directly from the bar, and having a hole completely through them. It is entirely practical to shear a slug or forging from a bar, carry it over into the die impression, and on the same stroke punch a hole through it, as indicated in "A" and "B" Fig. 8. This principle is adopted where a hole is desired completely through a forging. Reference to Fig. 9 shows that, in the last operation, the shearing of the forging from the bar takes place on the same operation in which the advancing punch punches out the remaining portion of the hole. The amount of scrap consists merely of the small slug punched from the bottom of the hole, as indicated at "A" Fig. 9. It is obvious, of course, that this same method can be adapted to forgings which have had several piercing operations for deeper holes, as indicated in Fig 10.

And there are many other applications of this new method. The present paper covers only a few. The fact that larger bars are used, and that any size of hole can be pierced or punched, overcomes the limitations of the previous method of upsetting and punching off the bar, which prohibited the production of "small hole work," or in other words, work where the area of the hole was small compared with the volume of the forging.

One of the advantages of this form of piercing is that while the length of the final piercers is considerable, they are in each operation supported by the walls formed by the preceding piercer, so that only a small length of each piercer extends unsupported beyond the face of the dies. If the gripping dies are rigidly held, so that the first upset is concentric on the shank, and the impression for the first piercer is correctly centered, then each succeeding piercer will be properly guided by the previously formed hole. Naturally, if piercers are not to be broken, there must be no raising, tumbling or wobbling of the heading slide. Accurate heading slide alignment for the piercers is absolutely essential. However, this alone would be useless, without sufficient rigidity in the grips to prevent spreading of the gripping dies under the upsetting

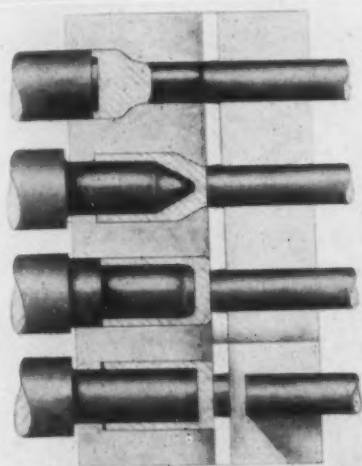


FIG. 7

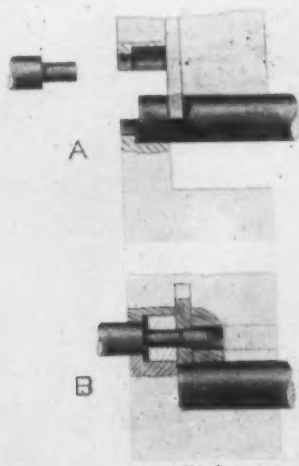


FIG. 8

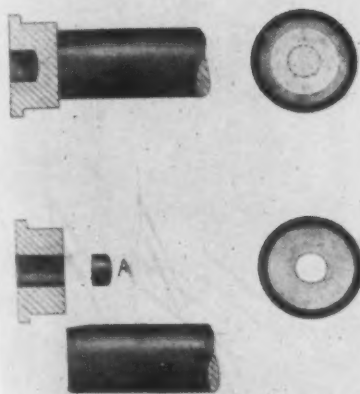


FIG. 9

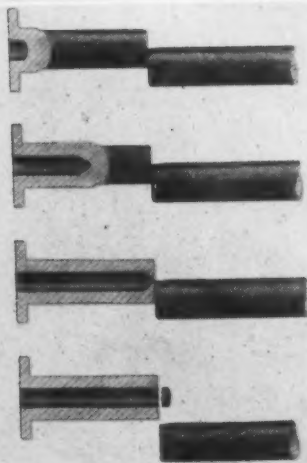


FIG. 10

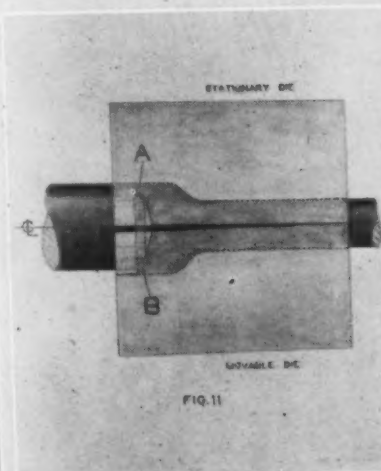


FIG. 11

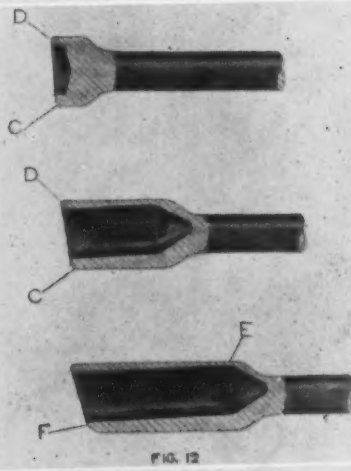


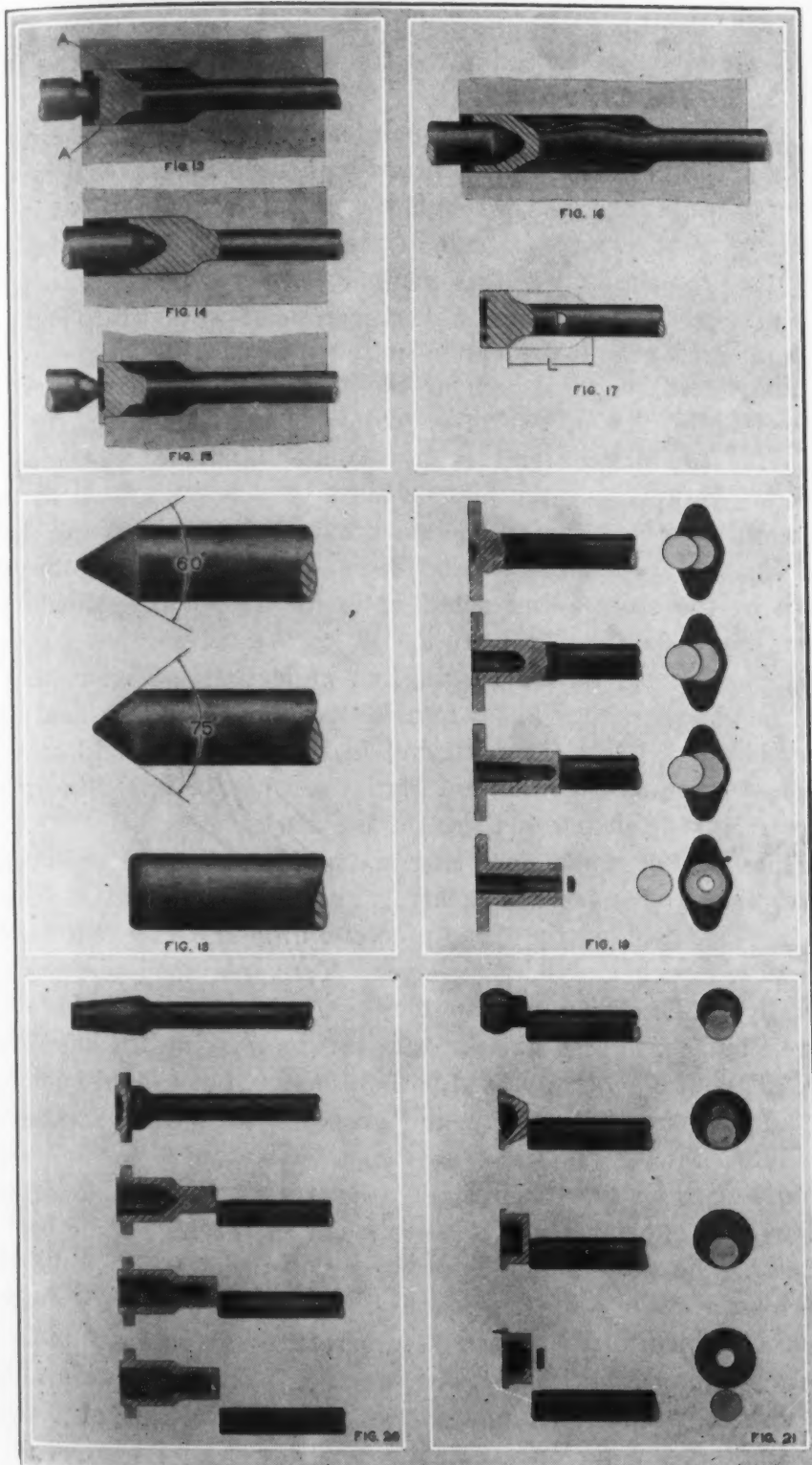
FIG. 12

action, because any spreading of the dies would make the upset eccentric, and the uneven side pressures on the piercers would cause them to drift. A top view of a movable gripping die which has spread open, is shown in Fig. 11. Naturally, the distribution of metal in the die impression is unequal, as shown at C and D, in Fig. 12. When the first piercer enters this eccentric upset, it will be called upon to exert a greater force in bending or deflecting the heavy section than the thin side. As a result, the piercer will "run" toward the thin side. For the same reason, in the next operation, the piercer will continue to run toward the thin side as at E, and a few repetitions of this are certain to break the piercer. In addition, the end of the forging will probably be dragged in, as at F. But with a positive grip which keeps the preparatory upset concentric, and with the first pierce central, subsequent piercing operations will remain central, as each hole serves as a guide for the next.

It must be remembered, also, that the principle of extrusion is not used in this work. Extrusion is possible on lead or brass, but is impractical on steel on account of the excessive wear on the punches and dies. At no time does the stock flow forward in the dies, as in extrusion. It is distinctly a piercing operation, and this demands that the stock to be pierced be held in a forward position in the dies. To accomplish this, the periphery of the upset portion must be gripped in the dies, as at (A) Fig. 13—the friction against the walls of the gripping dies serving to hold the upset portion in its forward position in the dies. If it is not sufficiently gripped or held, then the upsetting action of the piercer will push the stock back in the dies, as in Fig. 14, and the surplus stock in the bottom of the die impression will necessitate extrusion, and cause excessive strains and undue wear upon the piercer. A flange or shoulder at the front of the upset, as in Fig. 15, will, of course, serve to hold the stock in the forward position. Even a rather thin flange makes the gripping of the upset unnecessary; and luckily many forgings either have a flange, or only slight expense is caused in adding one. A trimming impression to remove it is a simple affair.

Another point to be remembered is that excessive depth of hole should not be attempted in a single piercing operation, as buckling of the bar will result from the upsetting action of the piercer, as shown in Fig. 16. The length of stock (L) in the open





(between the upset portion and the point where the stock is gripped) must not exceed three times the diameter of the stock (D), as in Fig. 17.

Attention to these few points, however, makes entirely practical the production of forgings with deep holes. And in view of the advantage gained through the use of larger sized bars; the opportunity to square the end of the forgings; and the excellent tool life now obtainable, this method creates a new era in forge shop practice—greatly increasing the scope of work which can now be made in a practical manner in forging machines.

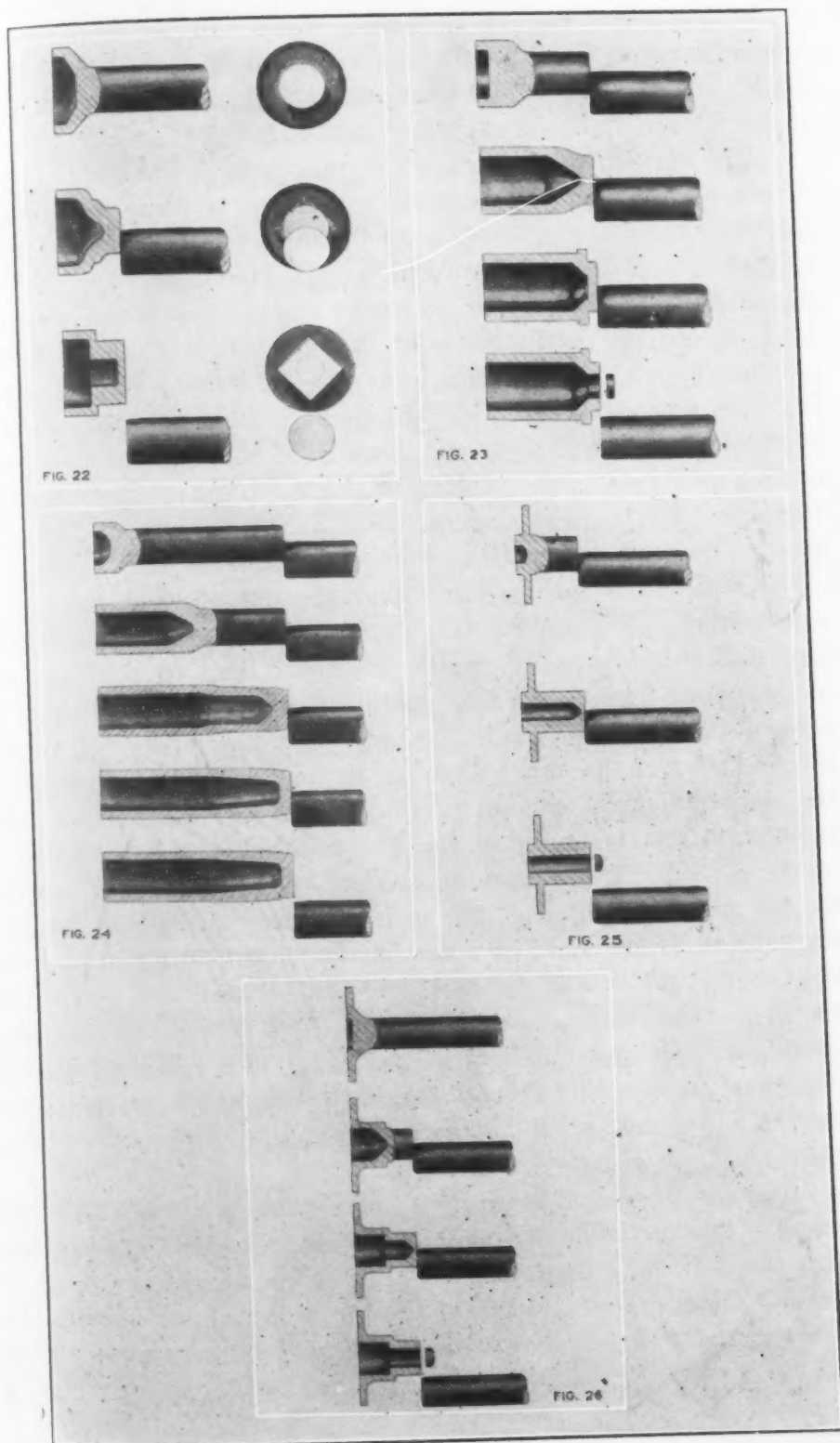
In regard to the design of the piercing tools, experience indicates that if the operation is merely that of piercing, the best angle for the piercer end is an included angle of not over 60 degrees. However, if the piercer must be used to square the end of the forging by pressing the stock against the end of the shear, then the included angle can be as much as 75 degrees; but the length of the stock being acted upon by this piercer should not exceed one diameter of the stock. If it is necessary that a square bottom be formed in the forging, as indicated in Fig. 5, then a square end tool with slightly rounded corners should be used; but the distance this tool should travel in the forging should only be sufficient to square up the end of the forging. Fig. 18 indicates, respectively, the shapes of these three tools.

Special, hot work, low carbon, tungsten steel is now used almost universally for hot shearing and punching tools. Such a steel is recommended for these piercers, although excellent results are secured with molybdenum steel. Tungsten steel piercers are generally air-hardened, for toughness; should test from 400 to 450 Brinell; and serve best when used without removing the hardening scale. They are generally used without water, but should be doped from time to time with tallow and graphite, white lead and oil, or other lubricant.

In regard to the forging temperatures for these piercing operations, the allowable range is governed in the high scale by the permissible heating temperature of the material, and in the low scale by the ability of the piercing tools to stand the required pressure. Generally speaking, temperatures from 1500 to 2100 degrees Fahr. are entirely practical; and it is such a wide range that makes possible, in many cases, the production of several forgings from the bar on one heat.

FIG. 22

FIG. 2

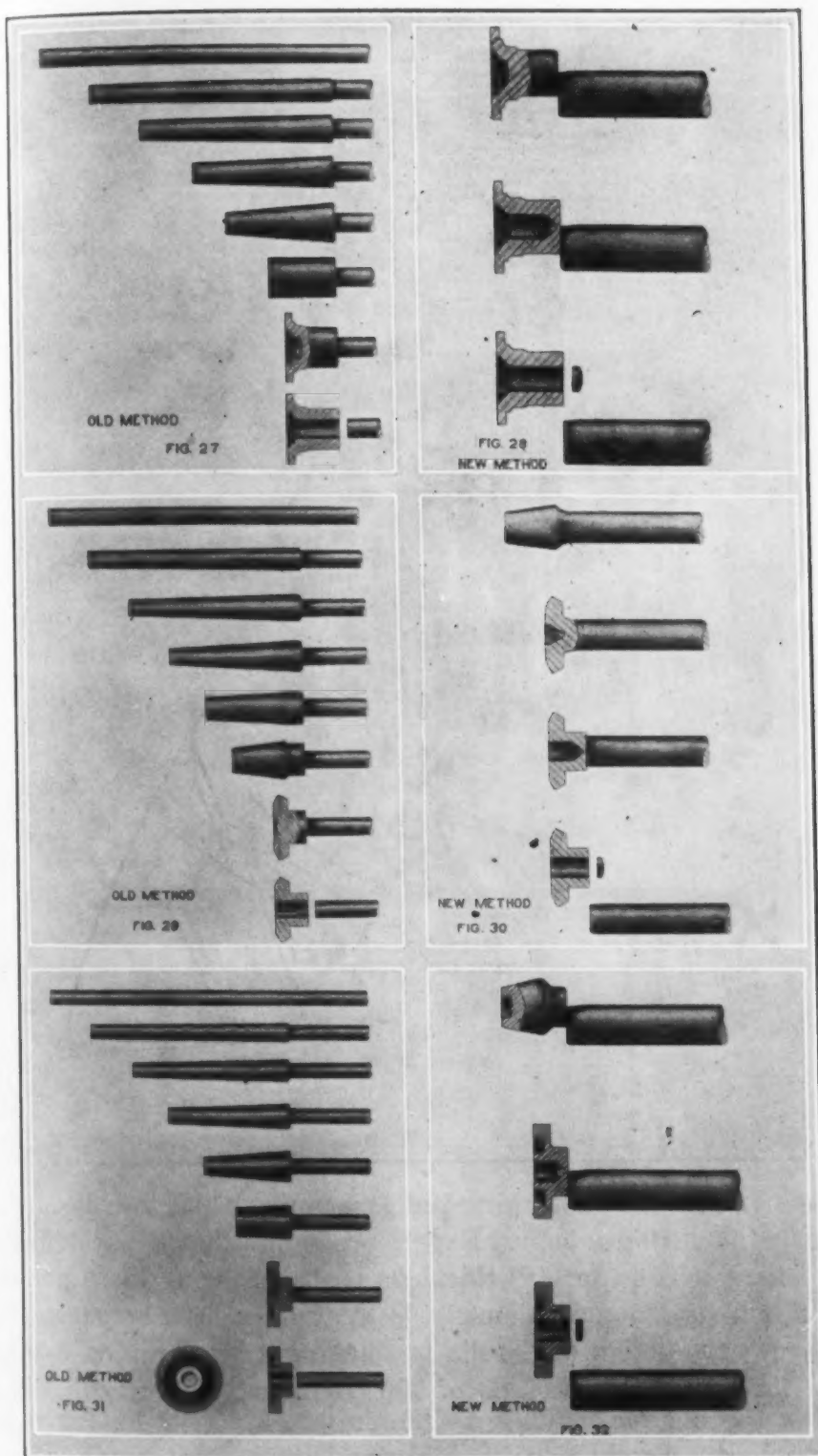


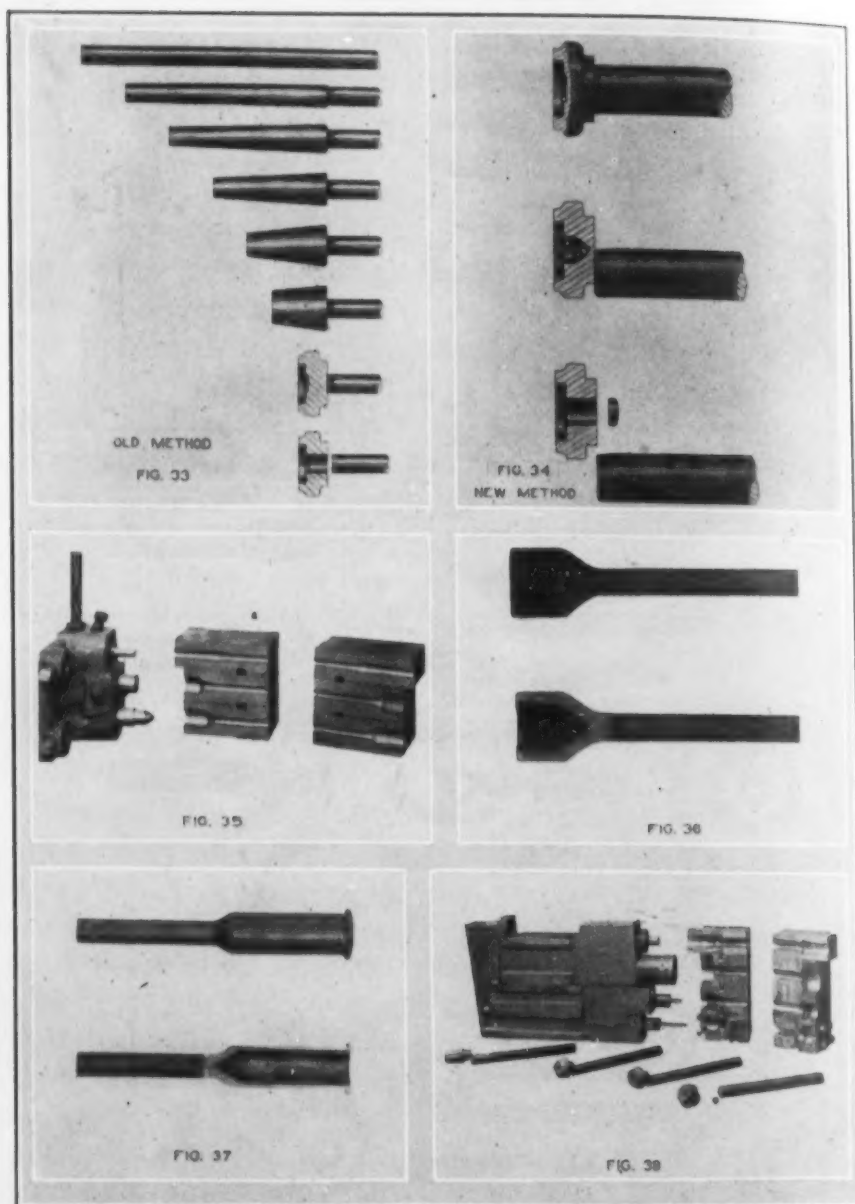
All straight carbon and alloy steels can be forged by this method, as well as all nonferrous metals which can be forged. The working temperatures and handling are the same as though forged under a hammer or by any other method.

The very broad application of this method to various types of forgings—many of which cannot, we believe, be forged by any other method—is indicated by Figs. 19 to 26. Fig. 19 shows the ability to make forgings with uniform outside diameters, but with two diameters in the hole. Fig. 20 shows that the outside diameter can vary, as well as the diameter of the hole. Fig. 21 shows a gland not forging with a hole through it. Fig. 22 shows a pipe plug forging with a solid bottom. Fig. 23 shows a forging with a shoulder at the base, and two sizes of holes. Fig. 24 shows the application of this principle to the making of high explosive shell forgings. Fig. 25 shows a flange forging with a hole through it. Fig. 26 shows a flanged hub, with two sizes of holes.

Keeping the fact in mind that the size of stock used in the new method corresponds to the cross-sectional area of the forging, and that this is usually greater than the area of the hole, it is obvious that fewer gathering operations are required than in the case of the old style method, in which the bar size used equalled the diameter of the hole. Frequently forgings were impossible by the old method, on account of the excessive length of small sized stock required, whereas, in the new method, the hole-size is immaterial. Fig. 27 is at least impractical by the old method, whereas, by the new method, Fig. 28, it is not only practical, but easy. Figs. 29 to 34 show old and new methods, indicating in each case the fewer operations of the new. As can be imagined, productions are larger by the new method, not only on account of the fewer operations required, but because the larger bars more readily hold their heat, and enable several forgings to be made before returning the bar to the furnace. The quick starting of the modern forging machine is, of course, essential.

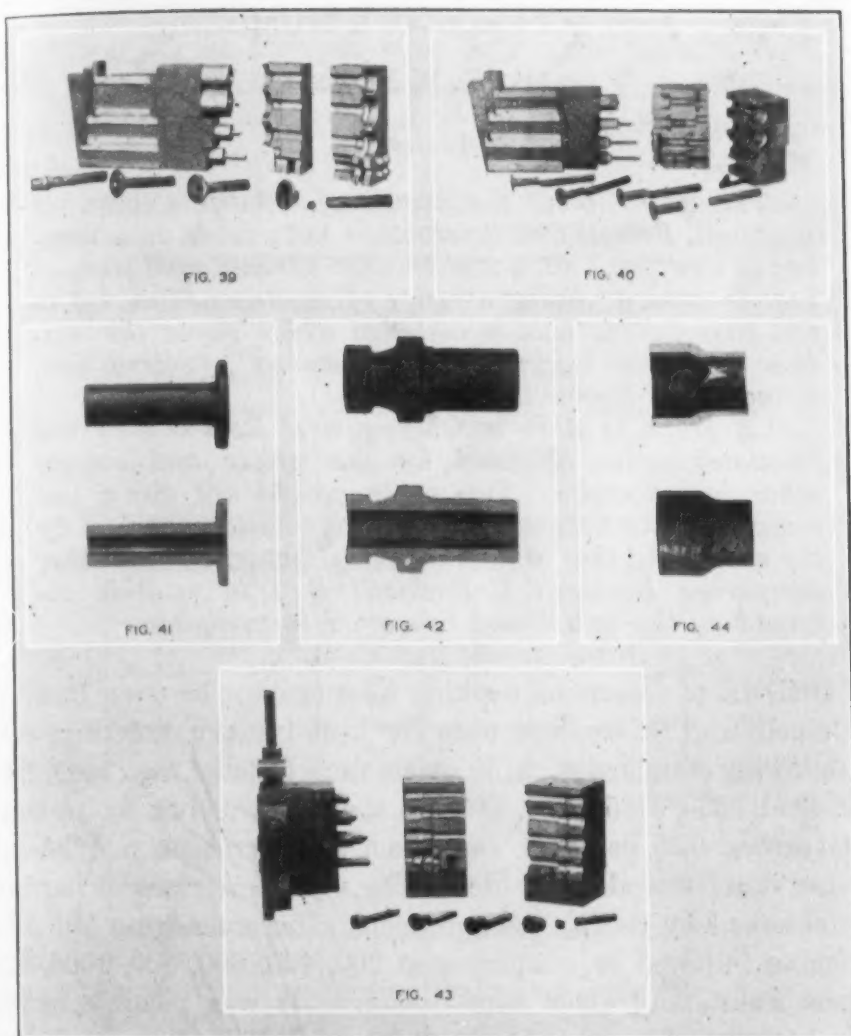
In fact, the high productions obtainable are one of the surprises of this method. Productions will be mentioned in connection with the following photographs. Fig. 35 is a photograph of the socket wrench die referred to at the beginning of this paper. The photograph in Fig. 36 shows this socket wrench and a sample which has been split. Production, 275 per hour. Photograph Fig. 37





shows the drag link forging and a sample which has been split. Production, 250 per hour. Experience shows that it is practical to hold the variation in wall thickness on this forging to 10 per cent, or in this case, to approximately 0.010 of an inch. Photograph Fig. 38 shows the design of the die for making a bevel pinion having a hole through it. Production of 250 per hour. Photograph Fig. 39 shows the die for making a differential side gear having a hole through it. Production of 175 per hour. Photograph Fig. 40

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shows the die for making a long sleeve forging, and Fig. 41 shows the forging and a split sample. Production of 200 per hour. The length of the hole in this forging is seven and one half times its diameter, and the piercer life is 8000 to 10,000 forgings per re-dressing. Photograph Fig. 42 shows a cluster gear made by this method, as well as a split sample. Production of 150 per hour. Fig. 43 shows the die for making the automobile wrench set forging, and Fig. 44 shows the forging and a split sample. Production of 300 per hour, as this forging is made on a small fast-running machine.

RELATIONSHIPS BETWEEN ROCKWELL, BRINELL AND SCLEROSCOPE NUMBERS

BY R. R. MOORE

Abstract

This paper gives the results of a large number of Rockwell, Brinell and Scleroscope tests made on a number of structural alloy steels under various conditions of heat treatment, giving a range of hardness from 145 to 625 Brinell. A table is included which shows the relation between Rockwell C (diamond), Scleroscope, Brinell, and Rockwell (B 1/16-ball).

A graph is given which compares Rockwell-Brinell relationships as obtained by the writer and several other investigators. Two other graphs are given, one comparing the Rockwell-Scleroscope relation obtained by the writer and that of another investigator, and the other comparing Rockwell C-Rockwell B 1/16 relation obtained by the writer and two other investigators.

IN ORDER to determine working relationships between Rockwell, Brinell, and Scleroscope tests for heat treated structural steels the following standard S. A. E. steels were tested: Nos. 1045, 2330, 3140, 3250, 3330, 3435, 6130, 6140. A special chromium-molybdenum steel (carbon 0.28 per cent, chromium 1.18 per cent, molybdenum 0.70 per cent) was also included. The various degrees of hardness were obtained by testing the specimens after quenching and after quenching followed by tempering at 200, 400, 600, 800, 1000, 1200 degrees Fahr., and after normalizing. It was possible by this method to cover a range of hardness from 145 Brinell to 625 Brinell.

The Rockwell-Brinell relationships were determined from tests made on square Izod impact specimens. These specimens are very desirable for Rockwell and Brinell tests because they are ground square with great accuracy.

Preliminary tests showed that the Izod specimen was too light for reliable Scleroscope tests so that a heavier specimen was adopted. This specimen was 1x1x3-inch ground square and finished smooth with 00 emery cloth. It was used throughout to determine the

A paper presented before the ninth annual convention of the society in Detroit, September 19-23, 1927. The author, R. R. Moore, a member of the society, has charge of the physical testing branch of the Wright Field, Dayton, Ohio. Manuscript received August 15, 1927.

Rockwell-Scleroscope relations and the Rockwell cone-Rockwell ball relations. These blocks however were only made from S. A. E. 3130, 3250, 6140 and cyclops steel (carbon 1.06 per cent). The Scleroscope tests therefore did not cover the high nickel-chromium or chromium-molybdenum steels.

The Rockwell tests were made with a No. 3B machine using

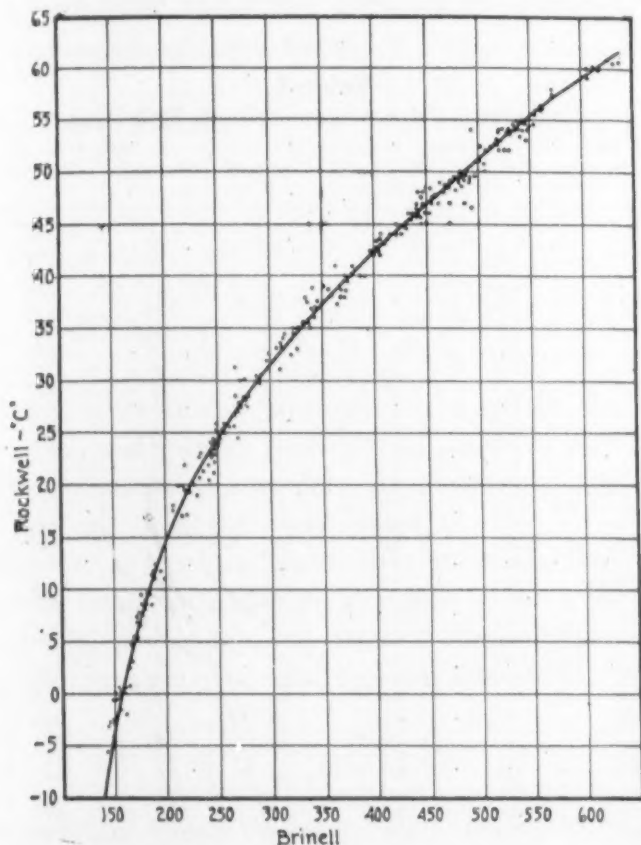


Fig. 1—Rockwell-Brinell Relationships.

the 120-degree diamond cone penetrator under a 150-kilogram load and the 1/16-inch ball penetrator under a 100-kilogram load. These values are designated as R_c and R_b respectively. The machine was checked against standard hardness blocks before and after each series of tests.

The Brinell tests were made with an Alpha machine. The load used was 3000-kilogram and it was held for 30 seconds. Hardness numbers were obtained from diameter readings which were taken to 0.01 millimeter.

The Scleroscope tests were made with a standard Shore Scleroscope of the vertical scale type (model C). The instrument was checked before and after each series of tests.

The results of the Brinell and Rockwell tests are shown in Fig. 1. The points represent the tests on the nine steels investigated, and give an idea as to the uniformity of the test results. This curve is a copy of the original plotting which was made on a graph sheet

Table I
Rockwell—Scleroscope—Brinell Relations

Rockwell C	Scleroscope	Brinell	Rockwell B $\frac{1}{16}$	Rockwell C	Scleroscope	Brinell	Rockwell B $\frac{1}{16}$
...	..	...	..	30	42	286	165
-6	..	145	..	31	43	294	166
-5	..	146	..	32	44	301	167
-4	..	148	..	33	45	309	168
-3	..	150	..	34	46	318	168
-2	..	152	..	35	47	327	169
-1	..	154	..	36	48	337	169
0	..	156	84	37	50	347	170
1	..	158	85	38	51	357	171
2	..	160	86	39	52	367	171
3	..	162	86	40	53	377	172
4	..	165	87	41	54	387	172
5	..	168	88	42	56	398	173
6	..	171	88	43	57	408	174
7	..	174	89	44	58	419	174
8	28	177	90	45	59	430	175
9	29	180	90	46	61	442	175
10	29	183	91	47	62	453	176
11	29	186	92	48	63	464	177
12	29	190	93	49	65	476	177
13	30	193	94	50	66	488	178
14	30	197	94	51	67	500	178
15	30	201	95	52	69	512	179
16	31	206	96	53	70	524	179
17	32	210	96	54	71	536	180
18	32	215	97	55	73	548	180
19	33	220	98	56	74	561	180
20	33	225	99	57	76	574	181
21	34	230	99	58	77	587	181
22	35	235	100	59	78	600	182
23	36	241	101	60	80	613	182
24	36	247	102	61	81	627	182
25	37	253	102	62	82	...	183
26	38	259	103	63	84	...	183½
27	39	265	103	64	..	...	...
28	40	272	104	65	..	...	...
29	41	279	104	66	..	...	...

about 20x30 inches in order to obtain greater accuracy in determining the final Rockwell-Brinell relationships. The Brinell and corresponding Rockwell values which represent this curve are given in Table I. They were determined from the original plotting and may show slight discrepancies from Fig. 1 due to inaccuracies in reproducing the curve on the smaller scale.

Fig. 1 is not a smooth curve. This can be more readily seen

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by plotting instead of direct Brinell numbers, the reciprocal of the $\frac{1}{2}$ power of the Brinell numbers as suggested by Petrenko¹. It will then be found that there are two points at which the curve assumes a marked change in direction; namely, $R_c=12$ and $R_c=44$. Evidently, for soft materials (below $R_c=12$) and for hard materials (above $R_c=44$) the relationship changes markedly. It is of little practical value but may be interesting to record the formulae representing these relations. They are as follows:

$$\text{For } R_c = 0 \text{ to } 12 \quad \frac{1}{\sqrt{B}} = 0.0804 - 0.000658 R_c$$

$$R_c = 12 \text{ to } 44 \quad \frac{1}{\sqrt{B}} = 0.0816 - 0.00075 R_c$$

$$R_c = 44 \text{ to } 60 \quad \frac{1}{\sqrt{B}} = 0.0722 - 0.0005357 R_c$$

Petrenko also found a marked change in direction for the hard material and locates this critical point at $R_c=40$ or 4 points lower than found by the writer. He, however, makes no mention of a low critical point for soft material.

A theoretical Rockwell-Brinell relationship has been developed by Petrenko, assuming that the hardness number is dependent only on the ratio of the load to the area of the indentation and is independent of the shape of the tool or the load. The relation is

$$B = \frac{C}{(100-R_c)^2}$$

The constant C can be determined theoretically from the characteristics of the indenting tool. The value of C determined in this manner does not of course check experimental results (as Petrenko shows) because the hardness number is in practice substantially affected by the shape of the tool and for many other reasons. Experimentally Petrenko has determined C to be 1,420,000 for values of R_c up to 40. The curve of Fig. 1 gives a value of $C=1,440,000$ over the medium hardness range. This appears to be a good check, but comparisons are better visualized from composite graphs as in Fig. 2.

The Rockwell-Brinell relationships as determined by S. P.

¹Relationships between Rockwell and Brinell Numbers—S. N. Petrenko, Bureau of Standards Technological Paper No. 334.

Rockwell² and I. H. Cowdrey³ together with those of Petrenko and the writer have been plotted in Fig. 2. Three of these curves are in very close agreement. The results obtained by Rockwell give either higher Rockwell for corresponding Brinell or lower Brinell

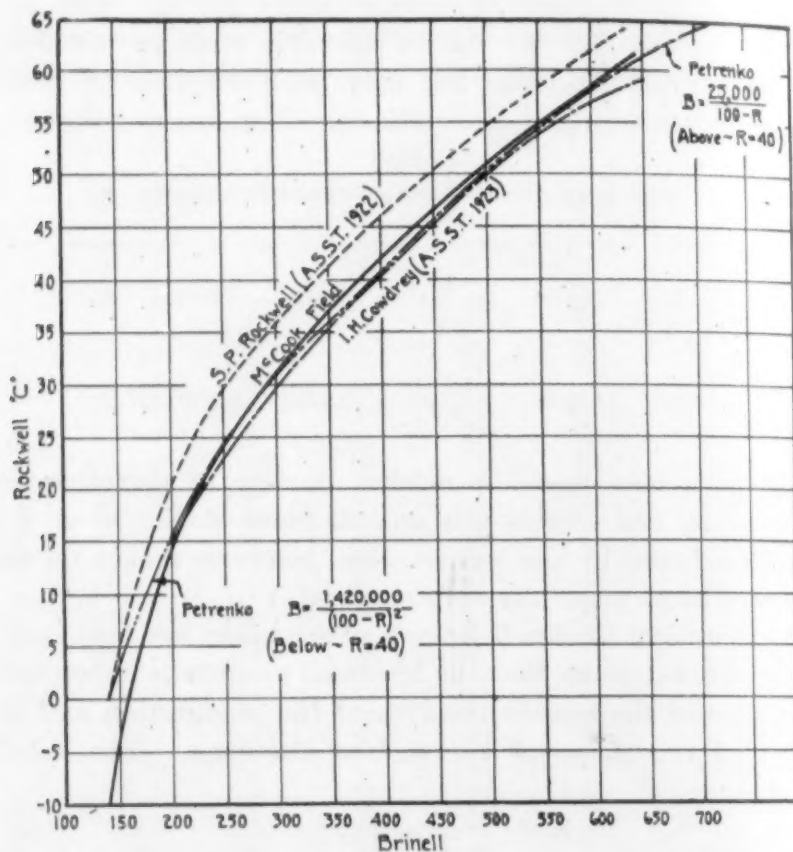


Fig. 2—Comparisons of Rockwell Brinell Relationships Observed by 4 Different Investigators.

for corresponding Rockwell. It is difficult to estimate which is the cause of the discrepancy. The results obtained by Cowdrey and the writer are within one Rockwell number until a Rockwell of 52 is reached, after which there is a greater divergence. However, even at $R_c=60$ the spread does not exceed three points. The results obtained by Petrenko also work in very closely, coinciding better at the higher hardness numbers than at the lower numbers. Considering that the Rockwell test itself under good operating con-

²The Testing of Metals for Hardness—S. P. Rockwell, TRANSACTIONS, American Society for Steel Treating, Vol. 2, August, 1922, page 1013.

³Relation Between Rockwell and Brinell Hardness Scales—I. H. Cowdrey, TRANSACTIONS, American Society for Steel Treating, Vol. 7, February, 1925, page 244.

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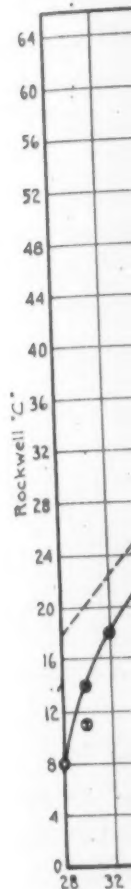


Fig. 3
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ditions may vary as much as two points these results are good checks.

The Rockwell-Scleroscope relationship is shown in Fig. 3. There is also included a curve plotted from the results obtained

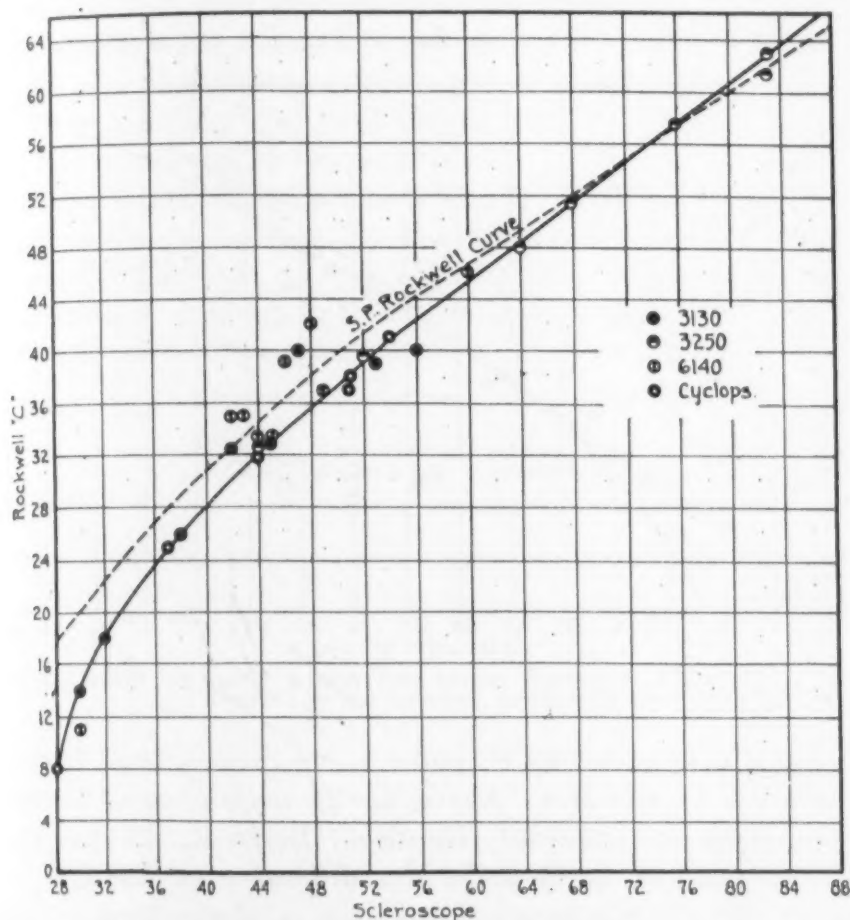


Fig. 3—Rockwell-Scleroscope Relationships, One Determined by S. P. Rockwell and the Other by the Author.

by S. P. Rockwell for comparison. The maximum divergence is found on the soft materials below $R_c=20$. Above this the curves converge and eventually cross. Above $R_c=36$ the discrepancy is not greater than two points on the Rockwell. In considering these results attention is directed to the fact that the tests made by the writer were performed on carefully ground blocks $1 \times 1 \times 3$ inches. It is felt that a specimen of about this mass is necessary for reliable Scleroscope values. The specimens used by S. P. Rockwell were $1\frac{1}{2} \times 1 \times \frac{1}{2}$. It is suggested that the difference in mass of the

two types of specimens may account for part of the discrepancy in test results.

Tests to determine the relation between the values obtained with the 120-degree diamond cone under 150-kilogram load and the 1/16-inch ball under 100-kilogram load were run, and results are shown in Fig. 4. There is also included a curve plotted from

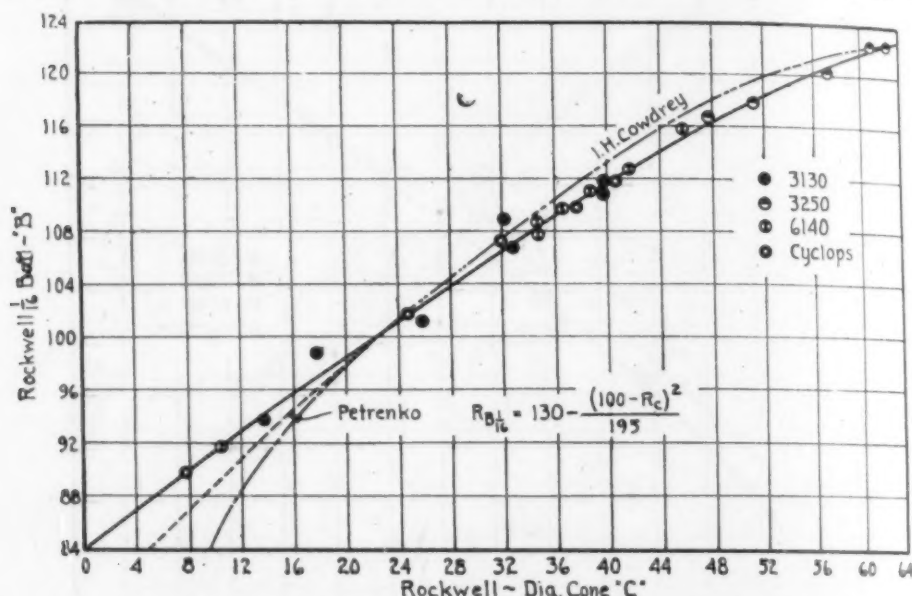


Fig. 4—Comparison of Rockwell 1/16-Inch Ball Reading Versus the Rockwell Diamond Cone Reading as Observed by Cowdrey, Petrenko and the Author.

the relation determined by Petrenko and a curve plotted from the results given by Cowdrey. Above $R_c=24$ the curves of Petrenko and the writer are practically identical. Below $R_c=24$ they begin to diverge until at $R_c=4$ there is a difference of $R_b=4$.

Tests with the 1/16-inch ball are given in tabular form by Rockwell. Selecting from his table both R_b and R_c values which correspond to a common Brinell number an R_b - R_c relation can be arrived at. The results fall even lower than those of Petrenko. However, the 1/16 ball tests by Rockwell were made on 0.077-gage brass sheet and the corresponding Brinell test was made under 500-kilogram load. It is believed that the low values were due to both the nonferrous metal and 500-kilogram load. Brinell numbers obtained by the use of 500-kilogram load are lower than numbers obtained with a 3000-kilogram load. With the method of selecting the corresponding R_b number this would operate to give a lower value.

The R_b - R_c with those of Below $R_c=24$ It is believed relations as of ferrous metals be mentioned as given by Cowdrey curve was repeated Formulae is generally in conditions. The average curve for general use

The R_b - R_c relations according to Cowdrey check fairly well with those of Petrenko and the writer for values of R_c above 24. Below $R_c=24$ the curves diverge with quite a spread at $R_c=8$. It is believed that this is due to the fact that the lower hardness relations as obtained by Cowdrey were predominantly for non-ferrous metals while those of the writer were for steels. It should be mentioned that it was difficult to accurately replot the curve as given by Cowdrey due to the small scale to which the original curve was reproduced in his paper.

Formulae and curves are desirable for detail study but a table is generally more valuable for use under most practical working conditions. For that purpose Table I was prepared from the average curves obtained in this investigation and is recommended for general use on ferrous metals.

NOTES ON THE SPARK TESTING OF STEEL

BY GEORGE M. ENOS

Abstract

It has long been known that the sparks given off when ferrous materials are touched to a rapidly revolving grinding wheel are characteristic of the composition and type of the iron or steel in question. This paper describes the technique of making such a test and the spark characteristics typical of a selected group of irons and steels.

INTRODUCTION

THE purpose of this paper is to review briefly the method of classifying irons and steels by means of the characteristic sparks which are given off as the various metals are touched to a rapidly revolving grinding wheel (3600 revolutions per minute). Each type or composition of steel produces certain spark characteristics which identify the material. By this method the carbon content of ordinary carbon steels may be estimated within fairly close limits. In alloy steels the alloying element or elements can usually be detected and an approximation made as to the percentage present. In cast metals, distinction is easily made between gray, white and malleable iron. The test is a useful one for such purposes as the sorting of mixed stock and the checking of material to be used for case carburizing, so that there may be no possibility of using high carbon steel for carburizing or low carbon steel for metal cutting tools.

John F. Keller, of Purdue University, was one of the pioneers in the study of spark testing. References in books and journal articles seem to refer mostly to his work. It seems probable that various companies have correlated spark testing and the chemical analyses of the steels they use, but there is little information of this nature in the literature.

SPARK CHARACTERISTICS

When a steel is held against a rapidly revolving grinding

A paper presented before the Cincinnati Chapter of the Society. The author, George M. Enos, a member of the Society, is in charge of metallurgy in the department of chemical engineering at the University of Cincinnati.

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wheel sparks are given off. The friction between the wheel and the metal is evidently so great that particles of metal and of the wheel are torn loose. The heat generated is sufficient to heat the metal particles to incandescence. The heated particles appear as sparks and these are thrown some distance from the wheel. The various elements in the steel will modify the color and bursting characteristics of the shower of sparks.

The volume of sparks will vary with the pressure exerted on the piece. The rate of travel of the sparks as they are thrown from the wheel will vary with the peripheral speed of the wheel. The temperature of the sparks and their bursting characteristics are believed to be independent of the factors just mentioned.

In alloy steels, the various sparks produced are probably best explained as being due to the characteristic flame color produced by the oxidation of the element or elements present.

The spark given off when a metal is made an electrode in a spark gap may be examined with a spectroscope and the characteristic bands noted. It is possible that this general method may be developed into a rapid means of testing alloy steels for their alloying metals.

In irons and steels there are certain microconstituents, the nature and quantity of which vary with the heat treatment which has been given to the material. It can be definitely shown that the heat treatment will have some influence upon the nature of the spark shower. Thus, if samples from the same bar be given different heat treatments, it will be possible to distinguish between annealed and hardened samples but not between samples given a mild quench and those which were tempered after a severe quench. The data on this experiment is given in Table I.

The change in the characteristics of the sparks in carbon steels is due to the change in the carbon content. If the sparks from very low carbon steel or from wrought iron be observed, it will be noticed that the sparks are long. The individual spark tends to follow a straight line, growing more luminous and broader as it advances. It disappears as it started. There is no forking or dividing of the spark. On observing sparks from steels of progressively increasing carbon content, it will be observed that more and more forking of the lines occurs.

Where little or no carbon is present in the iron, it probably

Table I
Tests on 0.6 Per Cent Carbon Steel

Test No.	Heat Treatment
1	Original Sample
2	Limit of furnace 1950 degrees Fahr.
3	1950 degrees Fahr. Annealed at at 1420 degrees Fahr.
4	<div style="display: inline-block; vertical-align: middle;"> <div style="display: inline-block; vertical-align: middle;">Iced Brine</div> <div style="display: inline-block; vertical-align: middle;">Water</div> <div style="display: inline-block; vertical-align: middle;">Oil</div> <div style="display: inline-block; vertical-align: middle;">Lead at 750 degrees Fahr</div> </div>
5	
6	
7	
8	<div style="display: inline-block; vertical-align: middle;"> <div style="display: inline-block; vertical-align: middle;">210 degrees Fahr.</div> <div style="display: inline-block; vertical-align: middle;">390 degrees Fahr.</div> <div style="display: inline-block; vertical-align: middle;">570 degrees Fahr.</div> <div style="display: inline-block; vertical-align: middle;">750 degrees Fahr.</div> </div>
9	
10	
11	

NOTES ON THE SPARK CHARACTERISTICS

- Nos. 1, 2, 3, regular spark characteristics of 0.6 per cent carbon steel
 No. 4, much greater spread or flare of the sparks, bursts seem to be more numerous and brighter
 No. 5, slightly less brilliant than No. 4, but easily distinguished
 No. 6, slightly less brilliant than No. 5, but easily distinguished
 No. 7, slightly less brilliant than No. 6, but distinguished from Nos. 1, 2 and 3
 No. 8, like No. 4 or 5
 No. 9, like No. 5 or 6
 No. 10, like No. 6 or 7
 No. 11, like No. 7

requires more time for the speeding particles of iron to become oxidized by contact with the air to a point where the heat of reaction is sufficient to produce luminosity. Once the particle is at such a temperature the iron simply burns. But when appreciable amounts of carbon are present, the heat generated in the oxidation of the iron, aids in starting the oxidation of the carbon. The carbides burn explosively, that is, forking, or deviations from the line of travel of the normal iron spark occurs in increasing amount as the carbon content of the steels under test is increased.

TECHNIQUE OF MAKING THE SPARK TEST

Probably the most convenient form of grinder to use is the small portable electric type, with a long cord which may be plugged in wherever a socket is available. The grit of the wheel does not seem to matter greatly. Excessively high speed 5000 revolutions per minutes or more should be avoided, but, of course, the grinder should run fast enough (3600 revolutions per minute) to generate

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the sparks. Schenck¹ states that the best results are obtained with a peripheral speed of 5000 feet per minute. Other types of grinders are, of course, suitable and may be used. It is best to protect the

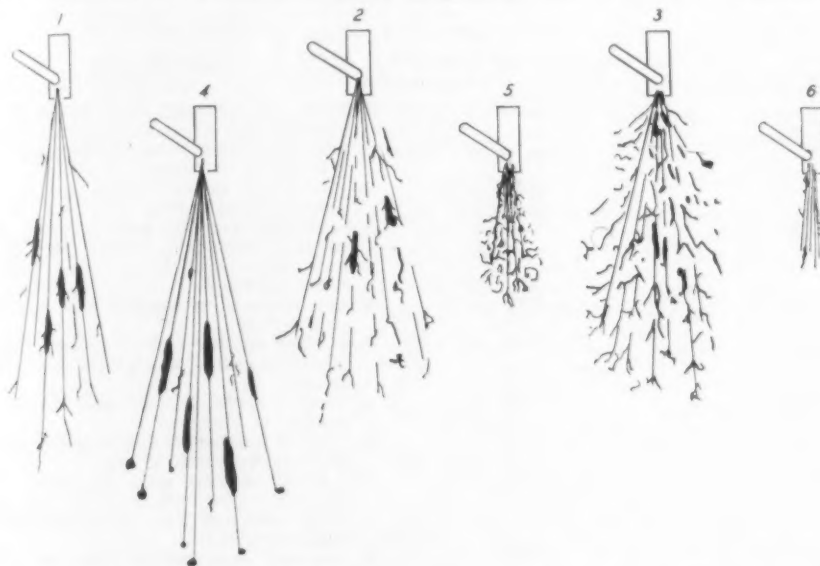


Fig. 1—Characteristic Sparks of Different Irons and Steels as Thrown Off by a Grinding Wheel. (1) Low Carbon Steel, (2) Medium Carbon Steel, (3) High Carbon Steel, (4) Wrought Iron, (5) White Cast Iron, (6) Gray Cast Iron.

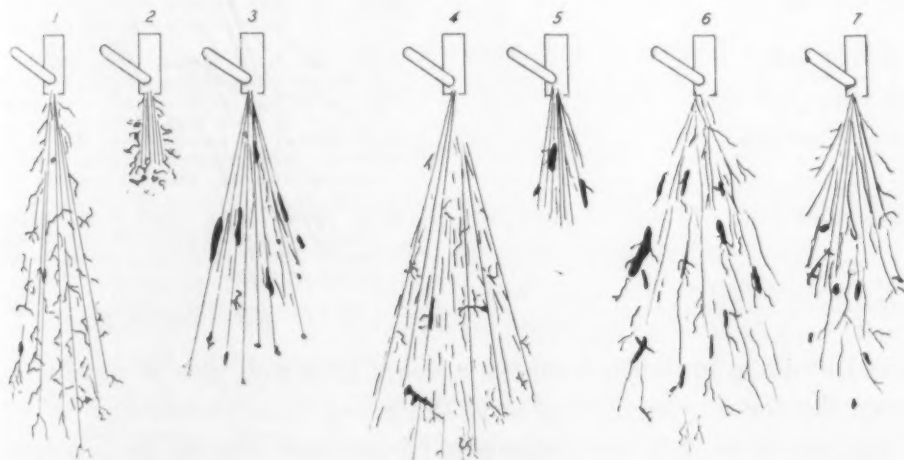


Fig. 2—Characteristic Sparks of Different Alloy Steels as Thrown Off by a Grinding Wheel. (1) Tool Steel, (2) Punch and Die Steel, (3) Heavy Duty Chisel Steel, (4) Hot Work Die Steel, (5) Stainless Iron, (6) Non-Shrinking Tap and Threading Die Steel, (7) Magnet Steel.

eyes with suitable goggles, as a protection from flying particles, and also to relieve the eye strain if much testing is to be done.

The steel should be touched lightly with the wheel (or vice

¹Schenck, R. B. Private communication.

Table II
Composition, Designation, and Spark Characteristics of Different
Irons and Steel

Name	Carbon Per Cent	Characteristics
Carbon steel	0.09	Similar to wrought iron in length of spark, light straw color, a few carbon bursts, about 1 burst per line, and 2 or 3 forks on the burst
Carbon steel	0.21	A few more carbon bursts than in the 0.09 per cent carbon
Carbon steel	0.30	The elongated sparks seem to curve more as they leave the wheel. The bursts have more side lines, i. e., there is more forking
Carbon steel	0.37	Slight increase in forking over 0.30 per cent carbon
Carbon steel	0.44	Increasing number of bursts, slight change in color to more of a golden tinge, more forking
Carbon steel	0.60	A copper-yellow colored spark, increasing number of bursts
Carbon steel	0.80	Increasing number of bursts and a marked decrease in length of travel.
Carbon steel	0.90	The color is more gold to white. The bursts are very numerous from the main spark, and the flare is thereby apparently increased
Carbon steel	1.00	In the very high carbon steels the carbon bursts and forkings are very numerous, and there is a tendency to shorten the length of spark, with a wider spray, and the color change is toward the red
Carbon steel	1.25	
Carbon steel	1.40	
Gray cast iron	...	Brick red, thin straight spark lines with only an occasional manganese and carbon burst
White cast iron	...	Spark like high carbon steel, but with brick red lines at the wheel
High silicon cast iron	...	Practically no spark at all, red flame perhaps $\frac{1}{4}$ inch long at the wheel
Malleable cast iron	...	Wide spread of sparks, short length of travel, some carbon bursts, marked forking of the lines, orange-red in color
Wrought iron	...	Long yellow lines, straight in center, forking somewhat at edge, no carbon bursts, usually balls or globules of fire at end of spark

versa) and the individual sparks noted. It is well also to produce a heavy shower of sparks and note the group characteristics. A set of specimens, plainly and permanently marked, should be provided as standards for comparison.

In observing the sparks the following points should be noted:

1. The length of travel of the spark
2. The distance from the wheel at which the spark becomes luminous
3. The amount and nature of the forking
4. The color of the spark.

Name
Tool steel
Punch and die steel
Hot work die steel
Heavy duty chisel
Stainless iron
Rustless steel
Drop forge and blocks
Non-shrinking tap threading die steel
Vanadium alloy steel
Magnet steel
Punch and die steel

*The chemicals furnishing the steel

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Table II (continued)

Name	Composition* Per Cent	Characteristics
Tool steel	High C. Cr 0.75 to 1.1, V 0.15 to 0.2.	High carbon sparks, finer bursts or flow-ers, probably redder lines
Punch and die steel	2.25 C. Cr 12.0, V 1.0.	Very short length, numerous fine bursts, orange to red color
Hot work die steel	0.65 C. W 13.5, Cr 3.75, V 1.0.	Short length sparks, fine carbon sparks, hot reddish, almost invisible lines
Heavy duty chisel steel	0.4 C. W 1.7, Cr about 1.0.	Short sparks similar to wrought iron except in length, few sparks, red lines, break at wheel
Stainless iron	C 0.07, Cr 17.0, Si 1.25.	Very short, faint reddish lines, breaking away from wheel, occasional iron sparks
Rustless steel	C 1.1 and as above.	As above, except evidence of higher carbon per cent
Drop forge and die blocks	C 0.55, Cr 0.5, Ni 1.5	No appreciable difference from steel of same carbon per cent except (possibly) in length of travel
Non-shrinking tap and threading die steel	C 1.0, Si 1.0, Cr 1.0, Mo 1.0, V 0.25.	Wide spread of curved lines, reddish-yellow bursts, similar in length and globules to wrought iron
Vanadium alloy steel	C 1.0, V 0.25.	Cannot distinguish from high carbon steel, except (possibly) by curving lines at wheel, finer carbon bursts
Magnet steel	C 0.65, W 5.5. Mn 0.2, Si 0.2.	Distinct red lines, and curved yellow streaks (short and away from wheel), few carbon bursts
Punch and die steel	C 0.55, W 2.75, Cr 0.8, Mn 0.25, Si 0.25.	Very red broken straight line with small carbon bursts at a distance from wheel

*The chemical composition is the approximate composition as indicated by the company furnishing the steel.

In Table II is given a list of steels and irons and their spark characteristics. Figs. 1 and 2 show typical spark figures.

CONCLUSIONS

An experienced observer, even without standards can classify carbon steels within 0.20 per cent carbon content without difficulty except, perhaps, in the very high carbon steels. He can also identify alloy steels, being able to distinguish chromium, vanadium, tungsten and report percentages within a per cent or so on most alloys. With the aid of a sufficient number of standard samples, he can do even closer work. Even an inexperienced observer, with the aid of standard samples, can classify steels fairly accurately and rapidly.

The previous heat treatment of carbon steels can be judged by characteristics of the spark, if an annealed standard sample of the same carbon content is available. This heat treatment test gives the condition of the steel rather than the exact history.

PREPARATION OF ALUMINUM OXIDE FOR FINAL POLISHING AND THE PRESERVATION OF POLISHED AND ETCHED SURFACES

By W. P. FISHEL

THE two processes described were developed in the Metallographic Laboratory of Vanderbilt University, Nashville, Tennessee.

A very fine grade of aluminum oxide for the final polishing of metallic samples can be prepared in the following manner. Carefully clean mechanically a sheet of aluminum and cut it into strips of such size that they may be placed in a beaker or other glass vessel. Wash the strips in alcohol to remove any grease, and immerse in a 10 per cent solution of mercuric chloride in water. When well covered with a thin coating of metallic mercury remove and rinse with water to remove any adhering mercuric chloride. Place the strips in a beaker of hot distilled water. It is not necessary that the strips be completely submerged. The reaction should be quite vigorous, hydrogen being evolved and aluminum oxide formed. If the beaker is almost filled with aluminum, the heat of reaction is sufficient to keep the contents near the boiling point of water, which condition is necessary for rapid action. The beaker and contents should be set aside for a few days. Add water occasionally to replace that used up. If the action stops, as it frequently does, it will be necessary to reamalgamate the strips, and proceed as before.

Oxide prepared in this manner approached the colloidal state in fineness and will remain suspended for several days. It, however, contains some finely divided mercury which gives it a dark color. To remove the mercury place in a tall vessel, and add enough water to form a thick suspension and agitate thoroughly to cause the particles of mercury to collect. After settling, the top portion may be drawn off. It is then ready for use.

PRESERVATION OF POLISHED METAL SURFACES

Polished and etched surfaces of metallographic samples may be

The author, W. P. Fishel, a member of the Society, is Assistant Professor of Metallurgy at Vanderbilt University, Nashville, Tenn.

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preserved for future examination, by coating them with a transparent lacquer of the cellulose-base type. Several commercial lacquers have been tried and found satisfactory. A suitable lacquer is made by removing the gelatine from a photographic film and dissolving the remaining portion (clear celluloid) in acetone, to make a solution having the consistency of varnish. The surface of the etched and dried sample is dipped in the lacquer and then allowed to stand until dry with the etched surface up and horizontal in order that the film will be of uniform thickness. The thickness of the film is regulated by the concentration of the lacquer. When dry the sample may be examined at low and medium magnifications. The film does not interfere with the vision except to give a slight yellow color which is most noticeable on the white constituents. It seems to make certain features, especially grain boundary lines, stand out more clearly. Several samples of malleable and gray iron, prepared four months ago, show no signs of corrosion, although they have been lying since their preparation on a shelf in the laboratory.

DEPARTMENT OF COMMERCE CO-ORDINATES MINERALS AND METALS SERVICES

The United States Department of Commerce has been surveying and co-ordinating its activities in the field of minerals and metals to the end that these industries may be able to obtain through the Department's facilities a broad international perspective. The economic structure of the post-war business world necessitates in practically every industry careful and constant study of world-wide conditions, and this is especially true of the minerals and metal industries.

The first step in rendering more efficient service in this direction has been the formation in the Bureau of Foreign and Domestic Commerce of a Minerals Division, which will supplement and assist in the work of the Economics Branch of the Bureau of Mines. This division, the nucleus of which is the former Minerals Section of the Foreign and Domestic Bureau's Iron and Steel Division, comprises three sections; Coal, Petroleum, and Minerals and Metals, each in charge of a specialist in these commodities.

The Minerals Division has been charged with the development and promotion of foreign trade in minerals and metals and their primary products and is responsible for the collection, compilation and dissemination of current foreign trade information. Its mineral and metal marketing specialists are the connecting links between these industries and the Bureau of Foreign and Domestic Commerce sources of information and services throughout the world, including fifty-one Bureau foreign offices and four hundred thirty-eight United States Consulates. The Bureau's fifty-

seven district and co-operative offices in the principal cities of the United States serve to keep the American manufacturer and exporter in more direct touch with the Bureau at Washington.

The mineral and metal industries also have at their disposal in the Bureau of Foreign and Domestic Commerce several special services which will now be more readily available to these industries through the Minerals Division. For example: The division of foreign tariffs advises concerning the customs duties of different countries and import and export regulations. The Bureau's experts in commercial law collect information concerning commercial laws of foreign nations, including the laws and rules relating to mining and industrial property. The finance and investment division keeps in close touch with the financial situation in all countries and is in a position to supply data concerning foreign investment opportunities. The division of statistical research collects trade statistics of foreign nations, and the division of statistics, in co-operation with customs officers, collects and compiles for publication statistics of the import and export trade of the United States. The transportation division compiles and furnishes information on foreign and domestic freight rates and packing methods. The commercial intelligence division provides lists of foreign importers and firms which are interested in American materials and maintains detailed reports on over 300,000 foreign merchants and manufacturers.

Aided by the Department's foreign offices the specialists and engineers of the Economics Branch of the Bureau of Mines will expand its researches into world-wide mineral occurrences and productions. Its several divisions specializing in coal, petroleum and other minerals, both metallic and nonmetallic, will continue to make studies of the economic problems of the mineral industries of the country and endeavor to aid in their solution. The Economics Branch will likewise carry on its studies and investigations into domestic resources, volume of production, consumption, distribution, stocks, commercial uses, trade conditions and similar subjects, and will continue to collect and disseminate statistical data relating to all of these subjects.

The minerals and metal industries of the United States also have at their disposal in the Department of Commerce several other services, each specializing in an important phase of these industries. The Bureau of Mines, Technologic and Health and Safety Branches, the Bureau of Standards and the Bureau of the Census function in this field.

The Bureau of Mines is, of course, the most important and is undoubtedly the best known to the mining industry. It is the province of this Bureau to study the methods of producing, treating and utilizing ores, mineral oils, gases and other mineral substances. The purpose is to reduce or prevent waste in the mining, quarrying, metallurgical, and other mineral industries and to conserve the country's mineral resources. Its specialists in technology make special investigations of the cause and prevention of mine explosions and major mine accidents. Its system of approved electrical devices directs attention to safe machinery for mining purposes. Its metallurgists and groups of eleven experiment stations and thirteen field offices in various parts of the country offer service in studying com-

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plex ores, the beneficiation of low grade ores, and the elimination of waste in metallurgical processes. The Health and Safety Branch directs a service of instruction in safety methods and mine rescue in case of disaster, through a system of five field offices and eleven well equipped railroad cars carrying specialized apparatus and skilled crews. This is supplemented by a system of ten fixed stations from which mine rescue trucks give similar service. Its safety specialists investigate safety practices in mines, and offer reports thereon when requested. Its surgeons make special studies of health conditions in mines, and the special health hazards of the mining and metallurgical industries.

The basic function of the Bureau of Standards is to establish and maintain national standards of quantitative measurement, although substantially half of the resources of this Bureau are expended in the testing of materials, instruments and equipment. Its metallurgy division has for its function investigational work with metals and alloys to determine their structure and behavior under various conditions and to establish specifications for standards of metals and alloys and determine their metallurgical constants and properties. It conducts investigations looking to improvement of metallurgical processes, such as annealing, tempering, casting and welding. Its clay and silicate products division makes investigations into the principles involved in the manufacture of clay and silicate products, including tiles, porcelain, glass, cement, etc.; the construction of refractories and the enameling of metals. It determines the formulae and specifications for standard qualities of such materials. Its division of simplified practice aids the various industries to standardize, as far as practicable, the grades, types and sizes of the commodities which they produce for market and the nomenclature applicable thereto, in order to reduce and eliminate wastes which result from excessive variety.

The Bureau of the Census periodically obtains and records special statistics of interest to the minerals industry, such as data pertaining to the country's mines, quarries, refineries, manufacturers, etc.

The Department of Commerce invites the Minerals and Metals industries to utilize its economic and technologic services to the fullest degree. Industry, however, should take the initiative in making its special needs known to the Department.

VOLUME XII COMPLETED

THIS issue of *TRANSACTIONS* completes Volume XII which covers the period from July, 1927, through December, 1927. Volume XIII will include the period from January, 1928, through June, 1928. The index for Volume XII is now ready for distribution and may be secured upon request.

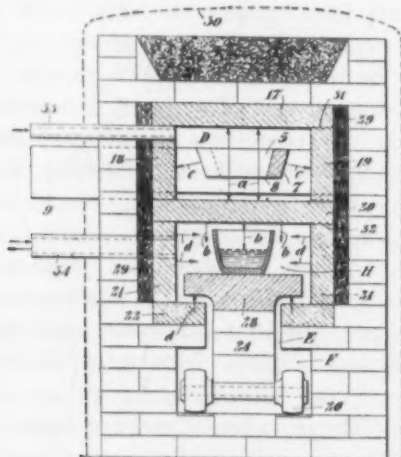
Those desiring to have their loose copies of Volume XII bound in accordance with the style used in binding Volumes I to XI inclusive, may do so by forwarding them to the executive office of the society, 7016 Euclid Avenue, Cleveland, together with \$2.00 and they will be bound and returned promptly.

Reviews of Recent Patents

By NELSON LITTELL, Patent Attorney
475 Fifth Ave., New York City—Member of A. S. S. T.

1,646,058, Electric Furnace, Francis A. J. FitzGerald, of Niagara Falls, New York, Assignor to Harper Electric Furnace Corporation of New York.

This patent describes an electric furnace of the tunnel kiln type in which the resistor chamber D is separated from the heating chamber H by a septum 20 of carborundum so as to permit the resistors 5 in the chamber



D to be surrounded with a non-oxidizing gas introduced through the tube 33 to prevent the deterioration which takes place in the presence of oxygen in the air, or of gases arising from the materials being treated. The heating chamber is formed to permit the passage of a truck 24, carrying the platform 28, for supporting the crucible "b" and is provided with a small clearance gap E below the platform 28 to prevent the escape of heat there-through. The tubes 34 communicating with the heating chamber may be used for the introduction of gases or for the withdrawal of gases from the heating chamber.

1,644,097, Manufacturing Edge Tools and Special Composition of Steel for Same, Arved Eduard Gaston Theophil von Vegesack, Munkfors Bruk, Sweden.

This patent describes an alloy for the manufacture of edge tools containing carbon from 0.7 to 1.1 per cent, chromium from 10 to 16 per cent, manganese from 0.75 to 2.0 per cent, and the remainder iron, containing the average percentages of other elements in technical iron. This alloy is fabricated in the usual way by hot rolling or forging and is softened for subsequent finishing by heating for several hours at about 1290 to 1470 degrees Fahr. (700 to 800 degrees Cent.). In heat treatment, it is preferable to cool in air from a high temperature and for increased hardness, to

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reheat to 750 to thirty minutes, increasing the heat about an increment

1,646,728, Assignor to the State of Virginia.

This patent has the purpose of providing a powder condition

sity of first fusion, the cupola has been into a ladle 13, is provided in the into the notch 14 flows from the hood 13 and a conveyor 18.

the fused slag dam 12 prevents and permits of

1,647,096, Wilmington, Delaware, Wilmington, Delaware.

This patent relates to grain and grain iron, carbon that usually is cent, preferably and hard like The alloy is nary gray iron to produce i

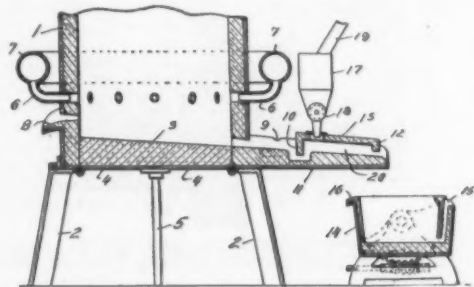
1,648,697, of Schenectady Corporation of New York.

This patent relates to steel, which

reheat to 750 to 930 degrees Fahr. (400 to 500 degrees Cent.) for about five to thirty minutes. The latter heat treatment step usually results in decreasing the hardness of a hardened steel, but in the present instance, brings about an increased hardness.

1,646,728, Refining of Iron, George S. Evans, of Oak Park, Illinois, Assignor to the Mathieson Alkali Works, of New York, N. Y., a corporation of Virginia.

This patent describes a process of adding soda ash to a cast iron for the purpose of refining the same which enables the soda ash to be added in a powder condition without escaping into the atmosphere and without the neces-



sity of first fusing or sintering the soda ash. In the drawing, 1 indicates the cupola having a sloping bottom 3 and a discharge spout 11 discharging into a ladle 14, in which the refining steps are to be carried out. A notch is provided in the discharge spout 11 and the dam 10 of a hood 13 projects into the notch 11 to prevent the escape of slag past the dam 10. The slag flows from the spout 9. The metal flows under the dam 10 and beneath the hood 13 and soda ash is added from the hopper 17 by means of the spiral conveyor 18. The heat of the iron fuses and sinters the soda ash so that the fused slag flows into the ladle 14 where it is mixed with the iron. The dam 12 prevents the escape of soda ash in powder form past this dam and permits only the sintered refined material to flow into the ladle.

1,647,096, Erosive Resistant Ferrous Alloy, Charles B. Jacobs, of Wilmington, Delaware, Assignor to E. I. Du Pont De Nemours & Company, of Wilmington, Delaware, a corporation of Delaware.

This patent describes a cast iron alloy of extreme hardness, fineness of grain and great strength, consisting of ingredients of cast iron, namely, iron, carbon in excess of 2 per cent with manganese greatly in excess of that usually present in cast iron, namely, in amounts between 3 and 15 per cent, preferably between 9 and 10 per cent. The new alloy is of fine grain and hard like chilled iron, but is stronger than either chilled or gray iron. The alloy is preferably produced by adding to the cupola mixture or ordinary gray iron a quantity of ferromanganese, or pure manganese sufficient to produce in the cast metal the desired manganese content.

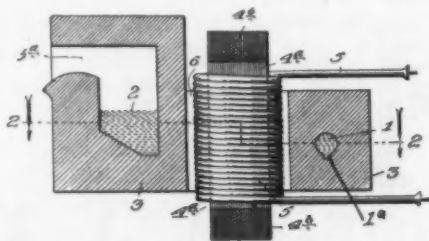
1,648,697, Process of Treating Magnetic Material, William E. Ruder, of Schenectady, New York, Assignor to General Electric Company, a corporation of New York.

This patent describes a method of heat treating magnetic or silicon steel, which comprises pickling the sheets for the removal of scale, washing,

drying and annealing in a vacuum or in hydrogen gas at a temperature from 1470 to 1560 degrees Fahr. (800 to 850 degrees Cent.) for about one hour. By this treatment, the magnetic permeability of the sheets, as compared with unpickled sheets, is increased about 10 per cent and the hysteresis losses decreased from 10 to 15 per cent.

1,646,862, Induction Furnace, William Hoskins, of Chicago, Ill.

This patent describes an induction furnace having a ring-like trough 1 surrounding the central leg 4-b of the transformer core and communicating with an enlarged chamber 2 at one side of the ring. To promote stir-



ring action and movement of the metal being heated along the ring 1, the ring is provided with a notch 1-a, which extends spirally around the ring 1 similar to the grooves in the rifling of a gun, so as to cause the bath to advance around the ring 1 following the direction of the spiral groove 1-a.

1,648,750, Process of Treating Iron, Irving R. Valentine, of Erie, Pennsylvania, Assignor to General Electric Company, a corporation of New York.

This patent describes a process of preparing malleable iron having a carbon content of 3 to 3.5 per cent, which comprises oxidizing the iron in a molten state, preferably in an electric arc furnace, to reduce the carbon content to about 2.50 to 2.75 per cent, thereafter treating the product with a reducing agent in the presence of a lime slag to reduce the carbon content to a negligible value, adding silicon to bring the silicon content to 0.8 to 1.0 per cent casting the metal and annealing the casting in the usual way.

1,643,808, Electric Furnace, Francis A. J. Fitzgerald, Niagara Falls, N. Y., assignor to Harper Electric Furnace Corporation.

In this electric furnace, an outer casing has a resistor chamber confined to its upper portion. A resistor extends through this chamber and radiates heat downward. A heat conducting structure distributes the heat supply to the articles on the conveyor located at the lower portion of the space within the casing.

1,641,764, Electric Furnace, William J. Keenan, Schenectady, N. Y., assignor to General Electric Co.

This electric furnace comprises heat refractory walls forming a heating chamber with supporting members provided with recesses secured to the walls on opposite sides of the chamber. The bars form heating elements extending across the heating chamber having their ends lying in the recesses and are electrically connected together to form a heating resistor.

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THE ENGINEERING INDEX

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Arrangements have been made with The American Society of Mechanical Engineers whereby the American Society for Steel Treating will be furnished each month with a specially prepared section of The Engineering Index. It is to include items descriptive of articles appearing in the current issues of the world's engineering and scientific press of particular interest to members of the American Society for Steel Treating. These items will be selected from the copy prepared for the annual volume of the Index published by the A. S. M. E.

In the preparation of the Index by the staff of the A. S. M. E. some 1,200 domestic and foreign technical publications received by the Engineering Societies Library (New York) are regularly searched for articles giving the results of the world's most recent engineering and scientific research, thought, and experience. From this wealth of material the A. S. S. T. will be supplied with a selective index to those articles which deal particularly with steel treating and related subjects.

Photostatic copies (white printing on a black background) of any of the articles listed may be secured through the A. S. S. T. The price of each print, up to 11 by 14 inches in size, is 25 cents. Remittances should accompany orders. A separate print is required for each page of the larger periodicals, but whenever possible two pages will be photographed together on the same print. When ordering prints, identify the article by quoting from the Index item: (1) Title of article; (2) name of periodical in which it appeared; (3) volume, number, and date of publication of periodical; and (4) page numbers.

ALLOY STEELS

AUTOMOTIVE INDUSTRY. Metallurgy and Motors, J. A. Mathews. *Indus. & Eng. Chem.*, vol. 19, no. 10, Oct. 1927, pp. 1089-1091. Contributions of metallurgists to automotive endeavor have been along two lines: first, production of new alloy steels; and second, development of methods to improve natural mechanical properties of those alloy steels by heat treatment; non-corrosive steels.

MOLYBDENUM. Facts and Principles Concerning Steels and Heat Treatment, H. B. Knowlton. *Am. Soc. Steel Treat.—Trans.*, vol. 12, no. 5, Nov. 1927, pp. 814-826, 3 figs. Discusses molybdenum and steels containing molybdenum; molybdenum as principal element in high speed steel has not met with much favor, but low amounts in conjunction with other alloying elements has proved very valuable in steels for engineering construction; it is claimed that molybdenum steels are inherently fine-grained, that they have a wide quenching range and they are not "temper brittle"; by proper heat treatment high degree of toughness in proportion to strength may be developed; hardening with relatively mild quenching, deep penetration of hardening effect, good forging and machining properties are among advantages claimed; properties and uses of specific types of chromium-molybdenum, nickel-molybdenum, and chromium-nickel-molybdenum steels, are discussed.

ALLOYS

ELECTRIC RESISTANCE VS. TEMPERATURE. A Method of Measuring Variations of Electrical Resistance for the Determination of the Thermal Equilibrium Diagram of an Inter-Metallic System, F. H. Jeffery. *Faraday Soc.—Trans.*, vol. 23, no. 78, Sept. 1927, pp. 563-570, 4 figs. Application of continuous method of measuring change of electrical resistance of alloy with change in temperature to series of copper-tin alloys

from 40 to 98 atomic per cent tin; the higher transition point of tin has been determined by this method to be 162 deg. Cent.

ALUMINUM

CASTINGS. Effect of Method of Molding on Properties of Castings of Aluminum and Aluminum Alloys (Ueber den Einfluss der Formart auf die Materialeigenschaften von gegossenem Aluminium und Aluminium-Gusslegierungen), W. Claus and F. Goederitz. *Giesserei-Zeitung*, vol. 24, no. 18, Sept. 15, 1927, pp. 516-520, 18 figs. Comparative tests of strength, hardness, fineness, etc., of ingots, green-molded and dry-molded castings of aluminum and of German and American aluminum alloys, showing improvements with decrease in grain size and strength in following order: ingot, green-mold, dry-mold.

CEMENTATION. Cementation of Aluminum and Duralumin after Double Electrolytic Deposition (Sur quelques cementations speciales de l'aluminium et du duralumin apres double depot electrolytique), J. Cournot and E. Perot. *Academie des Sciences—Comptes Rendus*, vol. 184, no. 21, May 23, 1927, 61927, pp. 1250-1252; and brief translated abstract in *Chem. & Industry*, vol. 46, no. 31, Aug. 5, 1927, p. 559. Cementation of aluminum and duralumin coated electrolytically with copper and then with nickel, chromium, cobalt, or cadmium was attempted by heating in sand bath or tubular electric furnace under varying conditions of deposition and cementation; total degree of penetration depends principally upon copper deposit.

COMMERCIAL. Commercial Forms and Applications of Aluminum and Aluminum Alloys, P. V. Faragher. *Am. Inst. Min. & Met. Engrs.—Tech. Publication*, no. 33, 1927, 28 pp., 5 figs. Commercially pure metal containing from 99.0 to 99.4 per cent aluminum, remainder consisting largely of

iron, silicon and copper introduced in process of electrolytic reduction, is called "pure aluminum" when it is desired to distinguish it from its alloy; effect of impurities in aluminum of high purity; uses for commercially pure aluminum; strong alloys; heat treatment; casting alloys; types of casting processes; sand casting alloys; effect of heat treatment on strength; permanent-mold castings; die castings; aluminum-alloy forgings and aluminum cable.

COMMERCIAL MANIPULATION. Some Aspects of the Commercial Manipulation of Aluminum, C. F. Nagel, Jr. Am. Inst. Min. & Met. Engrs.—Tech. Publication, no. 32, 1927, 21 pp., 6 figs. Presents illustrations of essential respects in which aluminum differs from other common metals, and emphasizes controlling factors of processes under consideration; deals with heat treating, annealing, cold forming, jointing by methods of soldering, welding and riveting.

CRYSTALLITES, ORIENTATION OF. Orientation of Aluminum Crystallites (Ueber die Kristalliten-Orientierung im Aluminium), G. Tammann and A. Heinzel. Zeit. für Metallkunde, vol. 19, no. 9, Sept. 1927, pp. 338-341, 3 figs. Comparative discussion of rolling of aluminum and of copper; orientation of crystallites in aluminum plates and change of orientation in accordance with temperature and degree of rolling; orientation of crystallites in sand and chill castings also in superheated chill castings.

DESTRUCTION BY MERCURY. Destruction of Aluminum by Mercury and Remedies (Aluminiumzerstörung durch Quecksilber und ihre Bekämpfung), H. Röhrig. Korrosion u. Metallschutz, vol. 3, no. 6, June 1927, pp. 121-123, 3 figs. Manganese and its soluble salts cause spontaneous destructive action on aluminum; mercury from thermometers and other apparatus is often source of this trouble; author has found that best remedy is 10 per cent potassium-bichromate solution which stops any further action of mercury by transforming it into oxide.

OXIDATION. The Film Produced by Anodic Oxidation of Aluminum, H. Sutton. Engineering, vol. 144, no. 3220, Sept. 30, 1927, p. 422. Describes experiments to isolate and identify film produced by anodic oxidation; method, results and properties of film.

RECRYSTALLIZATION. Recrystallization Effects in Aluminum (Rekristallisationsercheinungen bei Aluminium), A. E. v. Arkel and M. G. v. Bruggen. Zeit. für Physik, vol. 42, no. 11-12, May 16, 1927, pp. 795-806, 19 figs. Authors show that number of nuclei which form at given temperature varies with strengthening which is produced by previous deformation; grain size and deformation are not factors, velocity of growth decreases with deformation; explanation of presence of fine grains in Carpenter-Elam method of producing single crystals of aluminum.

SAND CASTING. Some Notes on Sand-Casting Aluminum. Mech. World, vol. 82, no. 2128, Oct. 14, 1927, pp. 290-291. Light weight of aluminum has always to be borne in mind, hence it must be fluid and poured quickly, and it must not meet much resistance from steam or air in mold; molds should be as dry as possible while still remaining workable, and they must be well

vented in places where gases of any kind would otherwise be able to form pockets.

ALDREY. "Aldrey"—An Aluminum Alloy (Aluminiumlegierung "Aldrey"), Fuchs. Zeit. für Metallkunde, vol. 19, no. 9, Sept. 1927, pp. 361-362. Chemical composition, method of treating, tensile strength, elongation, electrical conductivity and resistance to corrosion; also its use as an electric conductor.

ALPAX. Aluminum-Silicon Alloy "Alpax," and Its Application (Sur l'alliage d'aluminium et de silicium Alpax et ses applications), L. Guillet and S. de Lavaud. Académie des Sciences—Comptes Rendus, vol. 185, no. 5, Aug. 1, 1927, pp. 327-329. Alpax is light alloy of silicon and aluminum in eutectic proportions which is used for making molded articles on account of its small shrinkage after quenching; microscope shows fine structure of silicon grains in aluminum, but annealing even at low temperatures produces coalescence and impairs its mechanical properties; it may be refined before pouring by means of alkali fluorides and chlorides, and its mechanical properties then depend on temperature of pouring, rate of cooling, and amount of sodium present.

ALUMINA, INFLUENCE OF. The Influence of Alumina on the Casting Properties of Aluminum, F. Renaud. Foundry Trade J., vol. 37, no. 581, Oct. 6, 1927, pp. 12-14, 11 figs. Discusses alloys containing a high percentage of aluminum such as 92.8; deals with occluded and nascent alumina. Translated from Bul. of Association Technique de Fonderie.

ALUMINUM-COPPER. Industrial Utilization of Aluminum Alloys (A propos de l'utilisation industrielle des alliages d'aluminium), H. Pommerenke and P. Herman. Revue de Metallurgie, vol. 24, no. 6, June 1927, pp. 297-306, 6 figs.; and translated abstract in Metallurgist (Supp. to Engr.), Oct. 28, 1927, pp. 154-155, 2 figs. Results of investigation on tensile strength and hardness of binary copper-aluminum alloy containing 8 per cent copper; tests are designed to show that at all events for automobile industry such alloy cast under proper conditions, avoiding overheating, will in sand-cast state meet all ordinary requirements, and that for special conditions calling for greater strength, hardness and tensile strength of such an alloy can be economically increased 100 per cent by heat treatment.

ALUMINUM-SILICON. Equilibrium Relations in Aluminum-silicon and Aluminum-iron-silicon Alloys of High Purity, E. H. Dix, Jr. Am. Inst. Min. & Met. Engrs.—Tech. Publication, no. 30, 1927, 31 pp., 25 figs. Deals respectively with aluminum-silicon solubility equilibria and constitution of aluminum-iron-silicon alloys.

CASTINGS. Aluminum Alloys and Their Castings, W. Bannard. Metal Industry (N.Y.), vol. 25, nos. 9 and 10, Sept. and Oct. 1927, pp. 366-368 and 417-419. Current British practice in aluminum alloy castings.

HEAT TREATMENT. Heat Treatment of Aluminum-silicon Alloys, R. S. Archer, L. W. Kempf and D. B. Hobbs. Am. Inst. Min. & Met. Engrs.—Tech. Publication, no. 23, 1927, 30 pp., 35 figs. Results of experimental work and conclusions derived therefrom re-

garding heat treatment of aluminum alloys; properties of forgings, chill castings and "modified"

TRANSMISSION. Aluminum Alloy Transmission (Aluminium Alloy Transmission) vergütbar für die Freileitungstechnik, Zeitschrift für elektrische Krafttechnik, vol. 19, no. 11, 1927, pp. 1176-1177. Mechanical and electrical properties of per wires and alloys which are used for electrical transmission; some of mechanical properties of aluminum considered.

WASTE UTILIZATION. Produced in Light Alloys (Light Alloys) einwandfreie Herstellung von Leichtmetallen, Zeitschrift für Eisenhüttenwesen, vol. 48, no. 9, 1927, pp. 16-17. Advantages as an ingredient in aluminum steel.

AUTOMOBILE PLANTS

FORGING. Citroen Wins tion Methods, vol. 81, nos. 10 and 22, 1927, 717, 4 figs. partment. See continuously.

HEAT PRO. Synchronized i B. Nealey, 10, Sept. 8, Methods and heating steel

BLAST FURNACE

AUSTRALIA. Blast-Furnace Baker. Engrs. vol. 43, no. 1 (discussion) 2 construction a Reduction of use of incline coke hoppers with copper work; protected steel jacket support of lin at mantle, ring under u

OPERATION. Varieties of of Blast Furnaces des Einsatzes Betriebsbedin Bulle. Archiv 1, no. 3, Sept. ing types and other pr of iron pro penditure an nace commit Metallurgists

OXIDES. of the Blast

garding heat treatment of binary aluminum-silicon alloys; products heat treated included forgings, chill castings and both "normal" and "modified" sand castings.

TRANSMISSION CABLES, FOR. Aluminum Alloy Transmission Cables (Hochleitfähige vergütbare Aluminiumlegierungen in der Freileitungstechnik), Schmitt. *Elektrotechnische Zeit.*, vol. 48, no. 33, Aug. 18, 1927, pp. 1176-1180. Comparison between mechanical and electrical properties of copper wires and wires of various other metals and alloys which are being used for electrical transmission purposes; it seems that some of mechanical advantages of high conductive aluminum cables exceed cost consideration.

WASTE UTILIZATION. Utilizing Wastes Produced in Making Treatable Aluminum Alloys (Light Steels) (Zweckmässige und einwandfreie Abfall-Wiederverwendung der Herstellung vergütbarer Al-Legierungen), P. Scherber. *Zeit. für die Gesamte Giessereipraxis*, vol. 48, nos. 40, and 41, Oct. 2 and 9, 1927, pp. 165-166 and 169-170. Methods and advantages of re-using light steel scrap as an ingredient in the manufacture of light aluminum steel.

AUTOMOBILE MANUFACTURING PLANTS

FORGING AND HEAT TREATING. Citroen Wins with American Mass Production Methods, V. Delpont. *Iron Trade Rev.*, vol. 81, nos. 10, 11 and 12, Sept. 8, 15 and 22, 1927, pp. 594-595, 660-661 and 716-717, 4 figs. Sept. 8 and 15: Forging department. Sept. 22: Parts are heat treated continuously.

HEAT PROCESSES. Heating Processes Synchronized in Straight Line Production, J. B. Nealey. *Iron Trade Rev.*, vol. 81, no. 10, Sept. 8, 1927, pp. 584-587, 5 figs. Methods and equipment of Ford Motor Co.; heating steel ingots.

BLAST FURNACES

AUSTRALIA. Some Features of Australian Blast-Furnace Construction and Practice, D. Baker. *Engrs. Soc. of Western Pa.—Proc.*, vol. 43, no. 5, June 1927, pp. 255-261 and (discussion) 261-266. Noteworthy features of construction and practice in Australia are: Reduction of coke handling to a minimum by use of inclined coke bench and narrow-gage coke hoppers; protection of furnace hearths with copper cooling pipes laid in the brickwork; protection of bosh wall with a cast-steel jacket carrying bronze cooling plates; support of lining of blast furnace at bottom, at mantle, and with a secondary mantle ring under upper inwall.

OPERATION COSTS. Rating of Charge, Varieties of Iron, and Operation Conditions of Blast Furnaces (Wirtschaftliche Bewertung des Einsatzes, der Roheisensorte und der Betriebsbedingungen im Hochofenbetrieb), G. Bulle. *Archiv für das Eisenhüttenwesen*, vol. 1, no. 3, Sept. 1927, pp. 161-176. Expressing types and variations of mixing, charging and other processes of blast furnace methods of iron production in terms of heat expenditure and costs, reported by blast-furnace committee of Society of German Iron Metallurgists.

OXIDES REDUCTION. On the Theory of the Blast-Furnace Process, F. Wüst. *En-*

gineering, vol. 124, no. 3220, Sept. 30, 1927, pp. 436-438, 2 figs. Presents arguments to show that manganese, silicon, and phosphorus cannot be taken up by iron in any considerable quantity in blast-furnace bosh. Paper presented before Iron & Steel Inst.

PRACTICE. The Theory of the Blast-Furnace Process, F. Wüst. *Iron & Coal Trades Rev.*, vol. 115, no. 3109, Sept. 30, 1927, pp. 494-495, 2 figs. Presents arguments showing that manganese silicon and phosphorus cannot be taken up by iron in any considerable quantity in blast furnace bosh.

BRASS

CHARACTERISTICS. Characteristics of Brasses. *Am. Mach.*, vol. 67, no. 16, Oct. 20, 1927, p. 633. Rolled sheet and strip brass. Reference-book sheet.

HOT ROLLING. Problems of Hot Rolling Brass, L. Kroll. *Brass World*, vol. 23, no. 10, Oct. 1927, pp. 325-326. Larger heats in casting shop result in more accurate mixing and easier work with molds; critical review of hot-rolling literature.

PRESSED BARS. Heat Treatment and Structure of (a b) Brass (Die Wärmebehandlung und Gefügeausbildung von (a b)—Messing), R. Hinzmann. *Zeit. für Metallkunde*, vol. 19, no. 8, Aug. 1927, pp. 297-303, 12 figs. Formation of needle-shaped and granular structures of pressed bars due to temperature differences at time of pressing; subsequent heat treatment may only increase coarseness of granular structure; tests at cableworks laboratory of A. E. G. showing greater tensile strength and hardness of bars of granular structure.

YIELD POINT. Behavior of Brass at Yield Point (Über das Verhalten von Messing an der Streckgrenze), W. Koster. *Zeit. für Metallkunde*, vol. 19, no. 8, Aug. 1927, pp. 304-310, 9 figs. Buckling effect at yield point of heterogeneous copper-zinc alloys; influence of crystalline structure on form of elongation curve at yield point; heat treatment improves yield-point behavior of bars which had been previously stretched beyond elastic limit.

BRONZES

POROSITY. The Porosity and Physical Properties of Bronze (Ueber die Porosität und die physikalischen Eigenschaften des Rotgusses), Reitmeister. *Wärme*, vol. 50, nos. 30 and 31, Aug. 1 and 8, 1927, pp. 526-530 and 539-542, 15 figs. Details of experimental foundry of German State Railway; solidification processes in bronze alloys; testing of molding sand; practical testing of bronze alloys; relations between chemical composition and segregation tendency; physical properties of bronze.

CASE-HARDENING

IRON. Carburizing Iron By Mixtures of Hydrogen and Methane, W. P. Sykes. *Am. Soc. Steel Treat.—Trans.*, vol. 12, no. 5, Nov. 1927, pp. 737-754 and (discussion) 754-758, 27 figs. Determination of mixtures of hydrogen and natural gas (80 per cent methane) neutral to a steel of given carbon content at temperatures between 1470 and 2085 deg. Fahr.; carburizing action of various mixtures of hydrogen and natural gas on Armco iron at different temperatures.

LEAD COATING. Case Hardening: Lead Coating as Protection Against Absorption of Carbon (Einsatzhärtung: Verbleiung als Schutzschicht gegen C-Aufnahme), H. Graefe. *Werkstattstechnik*, vol. 21, no. 18, Sept. 15, 1927, pp. 521-523, 6 figs. Describes experimental studies, at Siemens-Schuckert plant, which led to development of process of lead coating of machine parts which are to be case-hardened; lead coating limits absorption of carbon by portions subject to tensile stresses.

NITRATION HARDENING. The Nitration of Steels (Sur la nitruration des aciers), L. Guillet. *Académie des Sciences—Comptes Rendus*, vol. 184, no. 22, May 30, 1927, pp. 1296-1299: Tests on nitrided complex steels show increases in hardness particularly with chromium-tungsten-vanadium steels, pearlitic and martensitic nickel-vanadium steels, and nickel-manganese steels; presence of vanadium, especially in nickel steels, has important influence.

PRACTICE. Practice in the Carburization of Steel, J. D. Gat. *Forging—Stamping—Heat Treating*, vol. 13, no. 10, Oct. 1927, pp. 393-396. Factors which exert influence on final product such as manner of packing, carburizing agents, energizers, etc.

CAST IRON

ABRASIVE RESISTANCE. Abrasive Resistance of Cast Iron (Die Abnutzung des Gusseisens und ihre Beziehung zum Aufbau und zu den mechanischen Eigenschaften), Kühnel. *Giesserei-Zeitung*, vol. 24, no. 19, Oct. 1, 1927, pp. 533-541, 24 figs. Laboratory and field tests of cast iron shoe brakes, valve rings, etc., showed that abrasive resistance of cast iron of ferritic structure is low; establishes relation between mechanical properties and abrasive resistance of cast iron; special study of grate bars, the effect of fire and sulphur upon them.

CARBON IN. Carbon in Cast Iron, P. Ropsy. *Foundry Trade J.*, vol. 36, no. 576, Sept. 1, 1927, pp. 199-204, 19 figs. Resume of certain practical studies and laboratory work. Paper read before the Brussels Congress of the A. T. F. B.

FLUIDITY OF. Spiral Test Bar Gages Fluidity of Cast Iron and Nonferrous Metals, C. Curry. *Foundry*, vol. 55, no. 20, Oct. 15, 1927, pp. 800-804, 10 figs. Review of experimental work to determine fluidity of casting alloys, with special reference to tests conducted under auspices of Assn. Technique de Fonderie de France by author with aid of suggestions by E. Ronceray.

FRENCH IMPROVEMENTS. The High Lights of the French Exhibition and Congress. *Foundry Trade J.*, vol. 37, no. 581, Oct. 6, 1927, p. 2. Improvements in cast iron; testing; melting problems; molding practice; constitution and preparation of sand; sand blasting; nonferrous foundry work.

GRAPHITE IN. Explains Graphite Formation in Gray Cast Iron, J. W. Bolton. *Foundry*, vol. 55, no. 19, Oct. 1, 1927, pp. 758-762, 18 figs. Calls attention to three dimensional forms of graphite and shows more common forms.

GRAPHITE IN. Strength and Structure of Cast Iron (Festigkeit und Gefügebau des Gusseisens), G. Neumann. *Stahl u.*

Eisen, vol. 47, no. 39, Sept. 28, 1927, pp. 1606-1609, 5 figs. Experimental study substantiating Bardenheuer; conclusions, showing great effect of graphitic content and structure on tensile strength of iron.

PEARLITIC. Evolution of Pearlitic Cast Iron (Entwicklung des Perlitgusses), Meyersberg. *V. D. I. Zeit.*, vol. 71, no. 41, Oct. 8, 1927, pp. 1427-1432, 14 figs. History of process since 1920, review of tests of mechanical properties showing its great superiority over other sorts of cast iron; data on its workability, resistance to abrasion, uniformity of structure, flawlessness, density, etc.

SEASONING. The Effect of Seasoning on Cast Iron, F. E. Cardullo. *Machy. (N.Y.)*, vol. 34, no. 3, Nov. 1927, pp. 199-200, 1 fig. Effect of slow cooling; changes in crystalline form; changing structure by annealing; time required for seasoning; outdoor seasoning.

SPUN-SORBITIC. "Spun-Sorbitic" Cast Iron. *Foundry Trade J.*, vol. 36, no. 576, Sept. 1, 1927, p. 195, 2 figs. It is centrifugally cast and is product of a new development in application of Hurst-Ball centrifugal casting process to production of cylinder liners, piston valve liners and other similar engine castings; designed to combine advantages of centrifugal casting process and low-silicon-content cast iron, having an "all pearlitic" structure for these purposes.

CASTING

CENTRIFUGAL. Flat Steel from Cammen Centrifugally Cast Bars. *Iron Age*, vol. 120, no. 16, Oct. 20, 1927, p. 1100, 2 figs. Experiments on a commercial scale of producing finished steel from centrifugally cast bars were carried out at plant of a large American steel company.

OIL ENGINE BEARINGS. Criticism of Oil Engine Bearings, R. Hilderbrand. *Power*, vol. 66, no. 16, Oct. 18, 1927, pp. 592-595, 7 figs. It is claimed that bearings should be redesigned; method of pouring babbit is declared faulty; author eliminates bearing shell, casting babbit direct.

STEEL RAILWAY PARTS. Casting Steel Railway Parts, E. G. Brock. *Can. Foundryman*, vol. 18, no. 9, Sept. 1927, pp. 5-9. Efficiency in production of cast-steel railway and electrical parts is achieved at Hamilton plant of Dominion Foundries and Steel, Ltd., by utilization of up-to-date equipment and simplification of operations.

CHAINS

MANUFACTURE. Heavy-Duty Chain Made by New Method. *Iron Trade Rev.*, vol. 81, no. 15, Oct. 13, 1927, pp. 897-898 and 908, 3 figs. Drop forging company in Worcester, Mass., has started production of weldless heavy-duty chain, patterned after design first worked out in connection with anchor chain for U. S. Navy; this new weldless chain develops on testing machine strength considerably greater than usual type of forged welded chain.

COKE

BLAST-FURNACE. The Effect of Varying Ash in the Coke on Blast-Furnace Workings, C. S. Gill. *Engineering*, vol. 124, no. 3220, Sept. 30, 1927, p. 435, 2 figs. Presents data obtained in practical tests showing

effect of variation applied to furnaces; produced, stove maintained as no effect of fluctuation ash. See also *Ga.* Oct. 1, 1927, pp.

COPPER

SULPHUR CO. Content on Properties über den Einfluss P. Siebe. *Zeit.* no. 8, Aug. 1927. Experimental study of SO₂ in causing injurious effect of creases ductility

COPPER AL

COPPER-TIN. Content on Some Metal Market, 1927, pp. 3-5, 1. tion to determine various times an on tensile prop as sand-cast.

COPPER-ZINC. of Commercial Bassett and C. & Met. Engrs. 1927, 16 pp., 1. are arranged to abling one at erties of copper characteristics hardness and gr in numerical va

CORROSION

OIL, BY. H. J. Young. 30, no. 16, Oct. 2 figs. Revolution and journal pit

CRYSTALS

FERRITE. McKeehan. *—Tech. Public* figs. Describes suggests, on smooth slip pla metal.

METALLIC

Metallic Singl Liempt. Am. I. Publication, n Methods are (1) from liqu state (3) elect tion in solid cussed.

CUPOLAS

HOT-BLAST Applied to th age, vol. 120, 27, 1927, pp. fig. Oct. 20: a point below combustion c Oct. 27: Cons 20 per cent; that required

effect of variation in quality of coke supplied to furnaces; ore mixtures, type of iron produced, stove temperatures, etc., were maintained as nearly constant as possible; effect of fluctuating ash and of consistent ash. See also *Gas World*, vol. 87, no. 2252, Oct. 1, 1927, pp. 33-34, 2 figs.

COPPER

SULPHUR CONTENT. Effect of Sulphur Content on Properties of Copper (Einiges über den Einfluss von Schwefel auf Kupfer), P. Siebe. *Zeit. für Metallkunde*, vol. 19, no. 8, Aug. 1927, pp. 311-315, 7 figs. Experimental study showing detrimental effect of SO_2 in causing blistering, and less injurious effect of CU_2S ; latter, however, increases ductility of metal.

COPPER ALLOYS

COPPER-TIN. The Effect of Heat Treatment on Some Mechanical Properties of 90:10 Copper-Tin alloy, R. J. Anderson. *Am. Metal Market*, vol. 34, no. 202, Oct. 19, 1927, pp. 3-5, 16 figs. Results of investigation to determine effects of annealing for various times and at different temperatures on tensile properties and hardness of alloy as sand-cast.

COPPER-ZINC. Physical Characteristics of Commercial Copper-Zinc Alloys, W. H. Bassett and C. H. Davis. *Am. Inst. Min. & Met. Engrs.—Tech. Publication*, no. 26, 1927, 16 pp., 12 figs. Data and plots given are arranged to constitute a summary, enabling one at glance to see physical properties of copper-zinc alloys to 62 per cent; characteristics shown are tensile properties, hardness and grain size, both in picture and in numerical values.

CORROSION

OIL, BY. Corrosion by Oil in Practice, H. J. Young. *Shipbldg. & Shpg. Rec.*, vol. 30, no. 16, Oct. 20, 1927, pp. 439 and 443, 2 figs. Revolutionary explanation of bearing and journal pitting.

CRYSTALS

FERRITE. Twinning in Ferrite, L. W. McKeehan. *Am. Inst. Min. & Met. Engrs.—Tech. Publication*, no. 29, 1927, 7 pp., 5 figs. Describes typical case of twinning and suggests, on basis of observed facts, why smooth slip planes are rarely observed in this metal.

METALLIC SINGLE. The Production of Metallic Single Crystals, J. A. M. van Liempt. *Am. Inst. Min. & Met. Engrs.—Tech. Publication*, no. 13, 1927, 8 pp., 4 figs. Methods are divided into following groups: (1) from liquid state; (2) from gaseous state (3) electrolytically (4) by recrystallization in solid state, each of which is discussed.

CUPOLAS

HOT-BLAST APPLICATION. Hot Blast Applied to the Cupola, F. K. Vial. *Iron Age*, vol. 120, nos. 16 and 17, Oct. 20 and 27, 1927, pp. 1071-1076 and 1155-1156, 4 figs. Oct. 20: Carbon monoxide drawn from a point below charging door is burned in combustion chamber preheating the blast. Oct. 27: Consumption of fuel and air reduced 20 per cent; blast pressure only one-half that required in ordinary practice.

LININGS. A Study of Cupola Lining Refractories, G. T. Schaller. *Can. Foundryman*, vol. 18, no. 9, Sept. 1927, pp. 16-17. It is necessary in order to study failures in cupola linings to consider all operating conditions, and to note different types of failures to which refractories are subjected.

LININGS. Rammed Linings for Cupolas. *Foundry Trade J.*, vol. 36, no. 579, Sept. 21, 1927, p. 264. States that a well-rammed lining may be expected to give good service for upwards of two years with a minimum amount of expenditure on patching.

LININGS. The Lining of a Cupola, F. Russell. *Foundry Trade J.*, vol. 37, no. 582, Oct. 13, 1927, pp. 24-25. It is claimed that monolithic linings are best; they should consist of a mixture of hard, comparatively large refractory lumps with a most refractory clay or other satisfactory binding medium.

ELECTRIC FURNACES

BRITISH PRACTICE. British Electric Furnace Practice, H. C. Dews. *Elec. Times*, vol. 72, no. 1876, Oct. 6, 1927, pp. 416-419, 5 figs. Operating costs; power supply; steel melting; melting mild steel; arc furnaces; electric pig iron; induction-type furnaces; Ajax Wyatt furnaces; Ajax Northrup.

HEAT-TREATING. Electric Furnace for Heating Drill Steel, H. K. Fox. *Forging—Stamping—Heat Treating*, vol. 13, no. 10, Oct. 1927, pp. 410-411, 2 figs. Electric furnaces used successfully to replace fuel-fired furnace for heat treatment of drill steel; construction of furnace and its advantages.

IRON INDUSTRY. Electric Heating in the Iron Industry (Elektrowärme in der Eisenindustrie), G. Bulle. *Archiv für das Eisenhüttenwesen*, vol. 1, no. 3, Sept. 1927, pp. 205-224, 25 figs. Report of heat engineering station of Soc. of German Iron Metallurgists, reviewing use of electric furnaces and other electric heating devices in ore dressing the blast furnace process, steelworks, rolling mills, steel treating plants, foundries, repair shops, boiler works, etc.

MELTING. High-Frequency Induction Melting, D. F. Campbell. *Elec. Rev.*, vol. 101, no. 2602, Oct. 7, 1927, pp. 607-609, 5 figs. Details of Ajax-Northrup high-frequency furnace. Abstract of paper read at Iron and Steel Inst.

ELECTRIC WELDING

SPOT. Multiple Spot-welding, Machy. (N. Y.), vol. 34, no. 2, Oct. 1927, pp. 103-104, 3 figs. Spot-welding machine installed by John Warren Watson Co., Philadelphia, increases production and gives higher quality work; makes six welds simultaneously by point or projection method.

ELECTRIC WELDING, ARC

BUILDING CONSTRUCTION. Arc-Welding in Buildings, J. Matte, Jr. *Am. Welding Soc.—J.*, vol. 6, no. 9, Sept. 1927, pp. 46-66, 25 figs. Describe structural engineer's experiences in this field of welding, gives his point of view of subject and makes suggestions which may be of assistance.

STRUCTURAL MEMBERS. Applies Welding in Constructing New Fabricating Shop. *Iron Age*, vol. 120, no. 18, Nov. 3, 1927,

that company; properties of a series of six gears, hardened by British firm using a Wild-Barfield electromagnetic furnace, are compared with those of series of six similar gear wheels, treated in two of best American electric furnaces, by Cadillac Company's employees.

MANUFACTURE AND HEAT TREATMENT. The Manufacture and Heat Treatment of Gears, F. A. Brooks. West. Machy. World, vol. 18, no. 10, Oct. 1927, pp. 471-475, 3 figs. Gear-tooth stress; manufacture of case-hardened gears; characteristic failures due to overstrain; microstructure; fracture at root of tooth.

HEAT TREATMENT

ELECTRIC. Selecting Electric Heat-treating Equipment, E. Fleischmann. Machy. (N. Y.), vol. 34, no. 2, Oct. 1927, pp. 123-125, 11 figs. Discusses heating elements, terminals, terminal connections, furnace voltage and furnace control.

OXY-ACETYLENE FLAME. Heat Treatment with the Oxy-Acetylene Flame, E. E. Thum. Am. Welding Soc.—Jl., vol. 6, no. 9, Sept. 1927, pp. 95-101, 7 figs. Advantages and possibilities of oxy-acetylene flame for heat treatment.

HOUSES

STEEL. Commercializing Steel Frame Houses. Iron Age, vol. 120, no. 17, Oct. 27, pp. 1146-1147, 3 figs. Large business interests will back erection of 500 steel frame dwellings for demonstration purposes in 100 cities.

HYSTERESIS

ALTERNATING STRESSES, UNDER. Hysteresis in Metals Under Alternating Stresses, N. P. Inglis. Metallurgist (Supp. to Engineer), Sept. 30, 1927, pp. 138-140. "Slip" effect in metallic crystals may be divided into two components, viz., beneficial slip and destructive slip; and capacity of a metal to be cold worked, its ability to redistribute stress by inelastic action, depends upon amount of beneficial slip which can take place in material; one of most convenient and simple means of detecting hysteresis effects during an endurance test is by using a rotating cantilever specimen and measuring deflection of end of cantilever in a plane perpendicular to that of imposed bending moment.

IRON ALLOYS

BRINELL BALLS, FOR. Discussion of G. W. Quick and L. Jordan's Paper Entitled "Iron Carbon-Vanadium Alloy For Brinell Balls", A. Hultgren. Am. Soc. Steel Treat.—Trans., vol. 12, no. 5, Nov. 1927, pp. 827-829. Includes authors' reply to discussion.

IRON-MANGANESE Desulphurizing Action of Manganese in Iron, C. H. Herty, Jr. and J. M. Gaines, Jr. Am. Metal Market, vol. 34, no. 182, Sept. 20, 1927, pp. 6-7, 2 figs. Review of experimental work and discussion of results.

Heterogeneity of Iron-manganese Alloys, C. R. Wohrman. Am. Inst. Min. & Met. Engrs.—Tech. Publication, no. 14, 1927, 38 pp., 45 figs. Melt of pure electrolytic iron with about 0.4 per cent sulphur and 7 per cent manganese was prepared in connection with

study of inclusions in iron; alloy darkened rapidly when etched with 10 per cent alcoholic solution of nitric acid, and microscopic examination revealed presence of semi-martensitic, semi-Widmanstätten structure closely resembling structures found by Benedicks in his artificially prepared "meteoric iron".

IRON AND STEEL

BEND TEST. A Critical Study of the Bend Test as Applied to Iron and Steel, A. B. Kinzel. Am. Soc. Steel Treat.—Trans., vol. 12, no. 5, Nov. 1927, pp. 778-791 and (discussion) 791-793, 10 figs. Theoretical study of strains produced on bending a rectangular bar; from theory there is deduced a method for quantitative evaluation of a bend test; phenomena of inside crack is investigated and relation between tensile and bend elongation is discussed; specifications for routing quantitative bend testing.

IRON CASTINGS

DIRECT METAL FOR. How Ford Uses Direct Metal for Motor Castings, P. Dwyer. Iron Trade Rev., vol. 81, no. 12, Sept. 22, 1927, pp. 711-714, 8 figs. In process lately placed in force, blast-furnace metal and cupola metal in approximate proportion of 40 per cent of former to 60 per cent of latter are poured into 400-ton mixer; from mixer metal is removed 15 tons at time and dumped into an electric furnace where it is raised to proper pouring temperature; it is taken from electric furnace in 1-ton ladles and distributed by monorail to various pouring stations.

GRAY. Who Can Solve the Gray Iron Problem? D. M. Avey. Foundry, vol. 55, no. 21, Nov. 1, 1927, pp. 836-839, 3 figs. Discusses future of gray iron.

STRESSES IN. Cause and Effect of Stresses in Castings, F. E. Cardullo. Machy. (N. Y.), vol. 34, no. 2, Oct. 1927, pp. 121-122. Stresses set up in castings as result of difference in temperature in various parts of casting at instant that part which solidifies last assumes its permanent form; factors that cause change in form of casting; shrinkage strains; effect of clamping and shrinkage strains; allowing work to cool between cuts.

IRON FOUNDING

MEDIEVAL. Founding in Tudor Days as Revealed by Testamentary Evidence, H. Littlehales. Foundry Trade Jl., vol. 36, no. 577, Sept. 8, 1927, p. 212. Account of will made by English citizens 400 years ago which throw a light on business of iron founding in Tudor days.

IRON METALLURGY

RESEARCH. Co-operative Research in Ferrous Metallurgy and the Problem of Inclusions in Steel, A. C. Fieldner. Engrs.' Soc. of Western Pa.—Proc., vol. 43, no. 5, June 1927, pp. 221-242 and (discussion) 242-254, 10 figs. Outlines co-operative research program of U. S. Bur. of Mines, Carnegie Inst. of Technology, and iron and steel industry as represented by Metallurgical Advisory Board.

IRON, PIG

BLAST-FURNACE TEMPERATURES, EFFECT OF. The Influence of Temperatures in

Blast Furnaces on the Carbon Content of Gray Pig Iron (Der Einfluss der Temperaturen im Hochofen auf den Kohlenstoffgehalt des grauen Roheisens), A. Michel. *Giesserei-Zeitung*, vol. 24, no. 20, Oct. 15, 1927, pp. 567-569, 2 figs. Flake-Graphite content of pig; influence of temperature and chemical composition of iron on carbon content; conditions governing production of carbon-poor iron.

CARBON IN. Carbon in Pig Iron. Am. Inst. Min. & Met. Engrs.—Tech. Publication, no. 11, 1927, 51 pp., 8 figs. Round-table discussion including following contributions: Need for Research in Foundry Pig Iron, R. Moldenke; Carbon Characteristics of Copper-bearing Pig Iron, W. B. Coleman; A pig iron, Low in Total Carbon, is in Demand for Use in Various Industries, E. Touceda; Carbon in Pig Iron, R. H. Sweetser.

SCRAP FOR. Chocsing Scrap for the Blast Furnace, D. McLain. *Can. Foundryman*, vol. 18, no. 9, Sept. 1927, pp. 13-14. Although gray-iron scrap has been used in manufacture of pig iron for many years, addition of plain carbon steel scrap is preferable, it being low in phosphorus and producing strongest pig iron.

SPECIFICATIONS. Propose Specification for Foundry Iron. *Foundry*, vol. 55, no. 21, Nov. 1, 1927, p. 846. Specification for foundry pig iron proposed by Federal Specifications Board.

MAGNESIUM

PROPERTIES. Physical Properties of Engineering Materials. *Power Engr.*, vol. 22, no. 259, Oct. 1927, pp. 385-386. Deals with history and physical properties.

MALLEABLE CASTINGS

ANNEALING. Better Boxes for Malleable Annealing, J. H. Hruska. *Iron Age*, vol. 120, no. 16, Oct. 20, 1927, p. 1086. Proper chemical composition essential; thermal deterioration must be considered; recommendations made.

CUPOLA. Metal for Malleable Iron Fittings Melted in the Cupola, L. E. Gilmore. *Foundry*, vol. 55, no. 31, Nov. 1, 1927, pp. 840-843, 4 figs. Production of desired quality in cupola malleable requires careful control over details of cupola construction and daily preparation; blast used; quality and quantity of fuel; raw materials; mixtures; control of sands for molds and cores; details of annealing operation and effect of temperatures, time and rate of cooling.

PROPERTIES. Malleable Cast Iron (La fonte malléable), M. Guedras. *Fonderie Moderne*, vol. 21, Mar. 25, Apr. 10, June 25 and July 10, 1927, pp. 30-32, 58-61, 185-191, and 210-213, 8 figs. Chemical composition of primary and secondary metal; physical and mechanical properties; forging, annealing and welding; composition of pig used in manufacture of malleable; ferroalloys. June 25: Manufacture of primary metal; cupola and reverberatory furnace melting. July 10: Electric furnaces; comparison of thermal balances; triplex process.

METAL SPRAYING

MOLTEN METALS. Coating by Molten-metal Spraying, R. L. Binder. *Machy.* (N. Y.), vol. 34, no. 3, Nov. 1927, pp.

169-175, 14 figs. Process of coating metals or other materials by spraying molten metal against surface to be coated; review covering latest forms of apparatus and some of typical, as well as more unusual, operations.

METALS

CEMENT AND GYPSUM, EFFECT OF. Effect of Cement and Gypsum on Light Metals (Die Einwirkung von Zement und Gips auf Leichtmetalle), J. Meyer and K. Pukall. *Chemiker-Zeitung*, vol. 51, no. 78, Oct. 1, 1927, pp. 757-758. Results of study, at University of Breslau, on influence of cement and gypsum on aluminum, magnesium, calcium and their alloys.

CRYSTALLIZATION. Historical Review of Crystallization of Metals (Geschichtlicher Beitrag zur Frage der Rekristallisation), J. Czochralski. *Zeit. für Metallkunde*, vol. 19, no. 8, Aug. 1927, pp. 316-320. Review of original literature on subject from 1853 to 1921.

INTERNAL STRESSES. Indication of Internal Stresses in Rods and Pipes (Der Nachweis innerer Spannungen in Stangen und Rohren), G. Sachs. *Zeit. für Metallkunde*, vol. 19, no. 9, Sept. 1927, pp. 352-357, 7 figs. Theoretical foundations and practical methods of process for determining internal stresses; layers of metal are turned off or bored out and changes in their length and thickness are measured; practical examples illustrating methods of measurement and computation of tangential and circumferential stresses from them.

PLASTIC DEFORMATION. The Plastic Deformation and Fracture of Metals, W. Rosenhain. *Engineer*, vol. 144, no. 3744, Oct. 14, 1927, pp. 422-423. Summarizes position of various problems relating to plastic strain and fracture as they stand today.

MOLYBDENUM

ELECTRIC-FURNACE RESISTORS. AS. Behavior of Molybdenum as Resistor in the Electric Furnace, H. J. Miller and M. Lindeman. *Am. Inst. Min. & Met. Engrs.—Tech. Publication*, no. 16, 1927, 13 pp., 18 figs. Life of molybdenum used as resistor was found to depend very much on manner of using it, its failure being due in some cases to thinning by evaporation or chemical reaction and in others to hardening, which prevented it from following expansions and shrinking of heating tubing without cracking; factors influencing behavior of molybdenum resistors.

NICKEL

ANNEALING. Nickel and Monel Metal, with Especial Reference to Annealing, C. A. Crawford. *Am. Inst. Min. & Met. Engrs.—Tech. Publication*, no. 35, 1927, 21 pp., 4 figs. Chemical composition; physical and mechanical properties; working and fabricating of nickel and monel metal; annealing; includes appendix on details regarding different classes of commercial nickel and monel-metal products.

NONFERROUS METALS

CASTINGS. The Future of the Non-ferrous Casting Industry, W. Lambert. *Foundry Trade J.*, vol. 37, no. 581, Oct. 6, 1927, p. 10. Deals with aluminum and aluminum-

alloy castings; m alloy castings; brasses.

ELECTRIC ME. ferrous Melting Gillett. *Foundry*, 1927, pp. 805-807. design and perfect ing nonferrous m 15 years.

VEHICULAR in Modern Trans Industry (Lond.) Sept. 16 and 27. Properties them valuable conveyances.

OPEN-HEAR

BASIC. Basic Embraces 960 F Trade Rev., vol. 17, pp. 773-777. of basic open-he totals 47,580,977 cerns are engag steel by open-he

MODERN TY Furnaces (Les Saigle. *Techniq* Oct. 15, 1927, eral review of operation of op Germany and A

OXYACETYLENE

AIR PLAN Fabricating F Oxyacetylene V vol. 81, no. 15, 2 figs. In its tion method determined upo much experime of United Stat concerns have this way strong be made with economy in la

PYROMETER

CERAMIC tions of Pyrom Great Britain. 2, Aug. 1927. general princi pyrometers in firing enamel

HEATED T

urement of sung von Ga Mitteilungen für Eisenforso no. 9, 1927, tion and num tion pyromete ture of aspira tact with an and observing has upon it; ience and p pyrometer; suggestion on

OPTICAL Pyrometer. Nov. 3, 1927

alloy castings; magnesium and magnesium-alloy castings; die-casting; high-tensile brasses.

ELECTRIC MELTING OF. Traces Non-ferrous Melting in Electric Furnaces, H. W. Gillett. Foundry, vol. 55, no. 20, Oct. 15, 1927, pp. 805-807. Traces progress made in design and perfection of equipment for melting nonferrous metals electrically during past 15 years.

VEHICULAR USES. Nonferrous Metals in Modern Transport, L. Aitchison. Metal Industry (Lond.), vol. 31, no. 11 and 12, Sept. 16 and 23, 1927, pp. 242-244, 269-272. Properties of nonferrous metals making them valuable for construction of various conveyances.

OPEN-HEARTH FURNACES

BASIC. Basic Open-Hearth Steel Industry Embraces 960 Furnaces, J. D. Knox. Iron Trade Rev., vol. 81, no. 13, Sept. 29, 1927, pp. 773-777. Estimated potential capacity of basic open-hearth plants in United States totals 47,580,975 tons annually; eighty concerns are engaged in manufacture of basic steel by open-hearth process.

MODERN TYPES. Modern Open-Hearth Furnaces (Les fours Martin modernes), J. Seigle. Technique Moderne, vol. 19, no. 20, Oct. 15, 1927, pp. 641-647, 12 figs. General review of recent practice in design and operation of open-hearth furnaces in France, Germany and America.

OXYACETYLENE WELDING

AIR PLANE-FRAME MANUFACTURE. Fabricating Frames for Airplanes by Oxyacetylene Welding. Iron Trade Rev., vol. 81, no. 15, Oct. 13, 1927, pp. 903-904, 2 figs. In its search for an efficient fabrication method American aircraft industry determined upon oxyacetylene welding after much experimentation; tests in laboratories of United States government and of private concerns have proved conclusively that in this way strong vibration-resisting joint can be made with minimum of weight and with economy in labor and materials.

PYROMETERS

CERAMIC INDUSTRY. Some Applications of Pyrometry in Ceramic Industries of Great Britain. Ceramic Age, vol. 10, no. 2, Aug. 1927, pp. 55-59, 6 figs. Describes general principles of pyrometers; use of pyrometers in glass and brick industry, for firing enamel colors, and for salt-glazing.

HEATED THERMOMETER TYPE. Measurement of Gas Temperatures (Die Messung von Gastemperaturen), H. Schmidt. Mitteilungen aus dem Kaiser-Wilhelm-Inst. für Eisenforschung zu Düsseldorf, vol. 14, no. 9, 1927, pp. 227-238, 30 figs. Description and numerous tests of modified aspiration pyrometer, which determines temperature of aspirated gas by bringing it in contact with an electrically heated thermometer and observing cooling or heating effect it has upon it; tests proved reliability, convenience and precision of this new type of pyrometer; critical discussion followed by suggestion on new methods of pyrometry.

OPTICAL. Improved "Pyro" Optical Pyrometer. Am. Mach., vol. 67, no. 18, Nov. 3, 1927, p. 713. Designed for par-

ticular use in measuring temperature of small glowing bodies, not inclosed and not having characteristics of black body, or for measurement of temperature of pouring metal.

TESTS. Pyrometric Methods for Oven Fired with Small-Coal (Die Messung hoher Temperaturen an Kohlegrüßöfen), W. Miehr. Tonindustrie-Zeitung, vol. 51, no. 60, July 27, 1927, pp. 1063-1068, 7 figs. Comparative experimental study of Hirsch and Miehr methods of measuring heat with hot wire pyrometers; found Hirsch method preferable; 5 per cent range of determinations; radiation pyrometers thought to be more suitable for ovens fired with small coal.

RAILROAD TRACK

TIES. Urges Broad Study of Steel Ties. Iron Age, vol. 120, no. 9, Sept. 1, 1927, pp. 559-560. Large outlet for steel in the early making, writer contends, if question is tackled by industry properly as sales-engineering-research job.

RAILS

CRACKING. Surface Cracking of Rails in Service (La fissuration superficielle des rails en service technique d'étude des rails fissurés), M. A. Portevin. Revue Generale des Chemins de fer, vol. 46, no. 9, Sept. 1927, pp. 263-275, 19 figs. Chemical and physical tests for determining character of temper and cold-rolling of rails with view of correlating with superficial cracking of rails in service.

CORRUGATION. Corrugation Studied at Montreal. Elec. Ry. J., vol. 70, no. 6, Aug. 6, 1927, pp. 224-226, 5 figs. Investigation indicates that character of rail surface is more influential than internal structure.

HAIR CRACKS IN. Hair Cracks in Steel Rails, J. H. Whiteley. Am. Soc. for Steel Treat.—Trans., vol. 12, no. 2, Aug. 1927, pp. 208-215 and (discussion) 215-220 and 234, 13 figs. This paper sets forth various tests made to detect internal flaws or defects in steel rails frequently described as hair cracks; two methods were employed, magnetization and treatment with dust in kerosene, and effect of reagent; chief features of interest which were revealed by microscopic examination are enumerated.

HEAT TREATMENT. The Heat Treatment of Steel Rails. Metallurgist (Supp. to Engineer), July 1927, pp. 104-105, 1 fig. Heat treatment of steel rails by the Sandberg process; abstracted from Rev. de Met., Jan. and Feb. 1927, pp. 10-19, and 68-78.

HEAT TREATMENT. Ways of Improving Rail Steel (Wege zur Verbesserung des Schienenbaustoffes), O. Pilz. Stahl u. Eisen, vol. 47, no. 40, Oct. 6, 1927, pp. 1645-1651, 13 figs. Reviews chemical and heat treating methods with special reference to Sandberg, Neues-Maisons, Ruhrort-Meiderich and Maximilian processes; comparative tests of rails treated by these processes critically discussed; practical experiences with rails treated according to these processes; resistance to wear as function of tensile strength.

NEW SECTION. The Reading Adopts A New Rail Section, J. C. Wrenshall. Ry. Eng. & Maintenance, vol. 23, no. 9, Sept. 1927, pp. 369-371, 7 figs. Modified head

with head-free joints shows marked advantages over common pattern.

WELDING. Second Year's Experience with Rail Welding in the Nürnberg Division of State Railway Administration (Das zweite Betriebsjahr der Schieneuschweißungen im Bezirk der Reichsbahndirektion Nürnberg). Schönberger. Organ für die Fortschritte des Eisenbahnwesens, vol. 82, no. 15, Aug. 15, 1927, pp. 275-279, 5 figs. Details of method of welding and 2 years' experience on an experimental stretch, 1289 m. long, showing highly satisfactory results.

REFRACTORIES

EFFECT OF SODIUM CARBONATE COMPOUNDS ON. Sodium Carbonate Compounds Affect Refractory Linings, G. S. Evans. Foundry, vol. 55, no. 16, Aug. 15, 1927, pp. 632-634, 5 figs. Nature and importance of the present development of the use of alkalis in foundry practice and effect upon refractories of a special sodium compound.

MAGNESIA. Magnesia Refractories For Steel Furnaces, G. M. Carrie and C. F. Pascoe. Can. Min. & Met. Bul., no. 186, Oct. 1927, pp. 1186-1272. Outlines occurrence of raw materials and indicates conditions under which finished product operates; nomenclature; uses; refractories available; applications; bibliography.

PROPERTIES AND REQUIREMENTS. The Important Properties and Requirements of Some Special Refractories, M. F. Beecher. Am. Soc. for Steel Treating—Preprint for 9th Annual Convention, Sept. 19 to 23, 1927, 12 pp., 2 figs. Author points out how fused alumina, silicon carbide and combinations of silica and alumina as now manufactured offer properties which are superior to those of clay refractories which are so extensively used.

SHRINKAGE. Studies Refractory Shrinkage, M. C. Booze. Iron Trade Rev., vol. 81, no. 16, Oct. 20, 1927, pp. 968-969. Contraction of fireclay brick is due largely to evaporation of mechanical water during drying and to attraction of single solid particles during initial burning and in use.

STEEL WORKS. Silica Bricks for Steel-works, A. H. Middleton and C. Bride. West of Scotland Iron & Steel Inst.—Jl., vol. 34, no. 5, Mar. 1927, pp. 64-71 and (discussion) 71-75. Chemical composition; methods of manufacture.

ROLLING MILLS

BAR MILLS. Bar Mill Designed Essentially for Alloy Steel Sections. Iron Trade Rev., vol. 81, no. 11, Sept. 15, 1927, pp. 662-666, 4 figs. Bar-piling device at hot bed retards cooling of material and permits stack annealing.

BAR MILLS. New Alloy Bar Mill at Chicago. Iron Age, vol. 120, no. 11, Sept. 15, 1927, pp. 729-731, 4 figs. New 12 and 16-in. alloy steel bar mill of Illinois Steel Co. at South Works, Chicago; guarding the quality of the steel and rolling to commercially exact dimensions prime considerations in laying out and equipping plant.

BEARING PRESSURES. Measuring Pressures on Bearings of Rolling Machinery, P. H. Frank. Iron Trade Rev., vol. 81, no. 16, Oct. 20, 1927, pp. 965-967, 3 figs. Two methods have been developed to determine

loads which anti-friction bearings must withstand.

BLOOMING AND SLAB. New Three-High Blooming and Slab Mill. Blast Furnace & Steel Plant, vol. 15, no. 9, Sept. 1927, pp. 441-443, 5 figs. Description of a mill built in Germany for an Italian works; method of operating discloses several novel features; all movements electrically controlled.

BRITISH PRACTICE. Some Features of British Rolling-mill Practice. Mech. World, vol. 82, no. 2124, Sept. 16, 1927, pp. 200-202, 6 figs. Status of rolling mill practice in Great Britain.

COLD ROLLING, COST REDUCTION. Reducing Production Costs in Cold Rolling Mills (Verminderung der Erzeugungskosten im Kaltwalzwerksbetrieb), H. Noleppa. Stahl u. Eisen, vol. 47, no. 32, Aug. 11, 1927, pp. 1317-1323, 5 figs. Operation and cost analyses and more or less specific remarks showing how by standardization modern industrial management, improvements, introduction of new machinery, purchasing pig iron by new specifications, etc. the duration of the rolling process can be cut in half and costs correspondingly reduced.

ELECTRIFICATION. Electrification of Rolling Mills, R. H. Wright. Elec. Jl., vol. 24, no. 9, Sept. 1927, pp. 419-426, 12 figs. Describes number of new electrically-driven rolling mills of modern design and construction recently placed in operation in Structural Dept. of Homestead Wks. of Carnegie Steel Co.

ELECTRIC DRIVE. Electrifies Finishing Mill Drives, J. F. Jelley. Iron Trade Rev., vol. 81, no. 6, Aug. 11, 1927, pp. 319-321, 1 fig. Replacement of engines at Phoenix Iron Co. augments production, decreases power costs, and improves uniformity of product.

ELECTRIC DRIVE. Electric Drive for the Reversing Mill at Margam Works. Iron & Coal Trades Rev., vol. 125, no. 3111, Oct. 14, 1927, pp. 563-564, 5 figs. Equipment consists essentially of 8000, 18,000 hp. d. c. motor driving mill; Ward-Leonard motor-generator set for control of mill motor; exciter set; high and low-tension switchboards; switchgear for operation platform, and an automatic slip regulator for a. c. motor of Ward-Leonard set.

ELECTRIC DRIVE. Recent Developments in Electric Drives for Rolling Mills, L. A. Umansky. Indus. Eng., vol. 85, no. 9, Sept. 1927, pp. 420-424, 8 figs. Describes several layouts for combination of electrical machines in various mills.

ELECTRIC DRIVE. Recent Developments in Electric Drives for Rolling Mills, L. A. Umansky. Am. Inst. Elec. Engrs.—Jl., vol. 46, no. 9, Sept. 1927, pp. 885-892, 12 figs. Electric drives, of capacities larger than encountered elsewhere, are usually designed to fit individual cases; special machines or special combinations of them are frequently used; several representative cases are outlined and methods of solving encountered problems are analyzed.

MACHINE BEARINGS. Economy of Bearings of Rolling Machines (Untersuchungen über die Wirtschaftlichkeit verschiedener Walzwerkslager), E. Cords. Stahl u. Eisen, vol. 47, no. 36, Sept. 8, 1927, pp. 1486-1489, 9 figs. Report of rolling mills committee of society of German iron metallurgists, deal-

ing with power intermediate, finishing using metallic wood bearings

OPERATION. Practice, G. A. 120, no. 9, Sept. 1927, pp. 120-121, 1 fig. Drafts for heavy, for proper eco-

PLATE MILL. ville & Sons. Works. Foundry, vol. 55, no. 13, Oct. 1927, pp. 582-583, 1 fig. for the manufa- of conversion i-

ROLLING AND FINISHING. of Solids When Rolling (Untersuchungen über das Walzen), N. M. tenwesen, vol. 204, 52 figs. mittee on rolling Iron Metallurg of various for phases; effect of temperature ternal stresses

SOAKING. on Recuperative vol. 81, no. 9, cause of success trial installati Co., Buffalo; Chapman-Steir

SPREADING. Layers in Breitungverla- ten von Wa- Pajunk. Sta- Sept. 22, 1927 of published perimental st of rolling p spreading al through cross

STRAIGHTENING. All Shapes richtmaschine S. Weil. Co- werke, vol. 437-440, 6 f of newest n of Duisburg, light and he-

STRIP MILL. Strip Mill. 15, 1927, pp. wide hot-str- June by Tr- stands and f- ings.

THIN SHEET. Krämer. In- nos. 3099, 3 Aug. 5, 1920. No- giving infor- and process portant inn- fers suggest-

WHEELING. N. Watkins vol. 15, no. Mesta Mach-

ing with power consumption of cogging, intermediate, finishing and high-speed rolling mills using metallic (plain and S. K. F.) pock wood bearings; shows superiority of latter.

OPERATION. Reversing Blooming Mill Practice, G. A. V. Russell. *Iron Age*, vol. 120, no. 9, Sept. 1, 1927, pp. 543-545, 3 figs. Drafts for heavy ingots; small-diameter rolls for proper economy; proportioning of roll passes.

PLATE MILLS. The Works of David Colville & Sons, Limited, Clydbridge Steel Works. *Foundry Trade J.*, vol. 37, no. 582, Oct. 13, 1927, pp. 35-36, 4 figs. Used for the manufacture of steel billets capable of conversion into high-explosive shells.

ROLLING AND FLOW OF SOLIDS. Flow of Solids When Rolled (Experimentelle Untersuchungen über den Materialfluss beim Walzen), N. Metz. *Archiv für das Eisenhüttenwesen*, vol. 1, no. 3, Sept. 1927, pp. 193-204, 52 figs. Experimental study, by committee on rolling mills of Soc. of German Iron Metallurgists on deformations of pieces of various forms in rolling through various phases; effects of non-uniform distribution of temperature, speed for rolling, etc.; internal stresses; discussion by members.

SOAKING PITS. Soaking Pit Operates on Recuperative Principle. *Iron Trade Rev.*, vol. 81, no. 9, Sept. 1, 1927, p. 501. Because of success of this type pit in France, trial installation was made at Donner Steel Co., Buffalo; it was designed and built by Chapman-Stein Furnace Co.

SPREADING. Spreading of Horizontal Layers in Rolling (Ermittlung des Breitungsverlaufes in den wagerechten Schichten von Walzkörpern), W. Tafel and G. Pajunk. *Stahl u. Eisen*, vol. 47, no. 38, Sept. 22, 1927, pp. 1562-1565, 8 figs. Review of published studies and report on experimental study by authors showing effect of rolling pressure and original width on spreading also distribution of spreading through cross-section of rolled piece.

STRAIGHTENERS. Straightening Rolls for All Shapes of Structural Steel (Rollenrichtmaschinen für alle Arten von Profilleisen), S. Weil. *Centralblatt der Hütten u. Walzwerke*, vol. 31, no. 32, Aug. 10, 1927, pp. 437-440, 6 figs. Construction and operation of newest models manufactured by Demag, of Duisburg, with one or two supports, for light and heavy sections.

STRIP MILLS. Trumbull Company's Wide Strip Mill. *Iron Age*, vol. 120, no. 11, Sept. 15, 1927, pp. 693-696, 6 figs. Describes new wide hot-strip mill placed in operation in June by Trumbull Steel Co.; ten horizontal stands and three edging mills; five finishing stands are four-high; large use of roller bearings.

THIN SHEET. Rolling Thin Sheets, W. Krämer. *Iron & Coal Trades Rev.*, vol. 115, nos. 3099, 3100, 3101, and July 22, 29, and Aug. 5, 1927, pp. 126-127, 164-165, 200-201. Notes on Continental practice, giving information concerning existing plants and processes, and touching upon some important innovations during recent years. Offers suggestions for further improvements.

Wheeling Steel Corp.'s New Skelp Mill, D. N. Watkins. *Blast Furnace & Steel Plant*, vol. 15, no. 9, Sept. 1927, pp. 435-437, 8 figs. Mesta Machine Company has designed new

type continuous electrically driven skelp mill using edging roll; special interest attached to new type electric flying shears.

WIRE AND ROD. Study of Wire-Rod Rolling Mills (Étude sur les trains à fils), E. Richarme. *Revue de Metallurgie*, vol. 24, nos. 4, 5, 6 and 7, Apr., May, June and July, 1927, pp. 161-178, 225-277, 307-316 and 405-407, 3 figs. Diameter of rolled wire; quality of metal to be rolled; weight of blooms and billets; multiple rolling; relation between section of rolled rod and tangential speed of cylinders; differences in dimension of rolled wire; determination of angular speeds of rolling mill; calculation of continuous mill; different types of mills; power of electric motors installed; rolling performance.

WOODEN BEARINGS. Wooden for Rolling Machines (Holzlager bei Walzwerken) A. Hülsewig. *Stahl u. Eisen*, vol. 47, no. 36, Sept. 8, 1927, pp. 1483-1485, 6 figs. Report of rolling mills committee of Society of German Iron Metallurgists; on basis of practical experience, recommends use of bearings of red brass with wooden cross-grain, cylindrical pins and stoppers, parallel and normal to bearing-axis, such bearings giving better service and lasting ten times as long as all-brass ones.

Control for Automatic Screw Down on a Rolling Mill, H. C. Jenks. *Elec. J.*, vol. 24, no. 9, Sept. 1927, pp. 446-451, 8 figs. Describes a recent application of automatic control to screw-down motors in large steel mill; by this means operators are entirely relieved of necessity of setting roll spacings to a particular point as determined by schedule, for each different pass.

ROLLS

BEARINGS. Bearings of Rolls (Walzenlagerung), C. Turk. *Stahl u. Eisen*, vol. 47, no. 35, Sept. 1, 1927, pp. 1437-1443, 10 figs. Wood and occasionally wood and red brass were gradually substituted for red brass bearings of rolls at Völklingen mill; wood bearings, provided with central lubrication, also cause saving in electric current; improvements in roller-bearings assure their future use in bearings of rolls.

SAWS

METAL CUTTING. Development of High Speed Steel Hack Saws or Cutting Off Saws, H. B. Allen. *Am. Soc. for Steel Treating—Preprint for 9th Annual Convention*, Sept. 19 to 23, 1927, 11 pp., 1 fig. This paper discusses application of high speed steel to machine hack saw blades; description of hardening process brings out some interesting properties of high speed steel not usually apparent when dealing with customary heavier sections; steel is shown to be plastic for some time after hardening, even when it is above hardness of 62-C Rockwell; neither does it attain full hardness for a considerable time after becoming quite cold; relative performance of saws made of high speed steel and low tungsten steel is also shown.

SHEET METAL

TESTING AUTOMOBILE BODY. Testing Automobile Body Sheet Steel, J. Winlock and G. L. Kelley. *Am. Soc. for Steel Treating—Preprint for 9th Annual Convention*, Sept.

19 to 23, 1927, 16 pp., 11 figs. Conditions governing making of stampings and results obtained in tests in which physical properties of steel are shown in their relation to its performance on the die.

SHEET STEEL

AUTOMOBILE BODIES, FOR. Testing Automobile Body Sheet Steel, J. Winlock and G. L. Kelley. Am. Soc. Steel Treat.—Trans., vol. 12, no. 4, Oct. 1927, pp. 635-650, 11 figs. Discusses conditions governing making on stampings and shows results obtained in tests in which physical properties of steel are shown in their relation to its performance on the die.

SILICON STEEL

BOSSHARDT FURNACE. Silicon Steel by the Bosshardt Furnace (Silizium-Baustahl aus dem Bosshardt-Ofen), K. v. Kerpely. Centralblatt der Hütten u. Walzwerke, vol. 31, no. 27, July 6, 1927, pp. 367-372, 7 figs. Reports results of tests of six samples supervised by State Institute for Testing Materials, showing that, with low carbon and manganese and equal working, new 10-ton Bosshardt furnace yields silicon steel of as good a quality as one from Siemens-Martin furnaces, and that tension elastic limit may be conservatively raised from 36 to 40 kg. per sq. mm.; drawings of Bosshardt furnace.

SPRINGS

STEEL, CORROSION OF. Protection of Steel Springs Against Corrosion. Mech. World, vol. 82, no. 2127, Oct. 7, 1927, p. 269. Discusses various methods for protecting springs, including: (1) painting; (2) oil finishing; (3) coating by molten metal, chiefly by tin; (4) electroplating; (5) non-metallic coating produced by boiling in special chemical solution often sold under trade name.

STEEL

COLD-WORKED. Plastic Flow and the Strength of Cold-Worked Steel, E. B. Norris. Eng. News-Rec., vol. 99, no. 14, Oct. 6, 1927, pp. 548-549, 3 figs. Stress referred to reduced cross-section; test results; correlation of stress and reduction of diameter.

DECARBONIZATION. Decarbonization of Carbon Steels (Ueber die Randentkohlung von Kohlenstoffstählen), W. Hülsbruch. Archiv für das Eisenhüttenwesen, vol. 1, no. 3, Sept. 1927, pp. 225-240, 45 figs. Communication from experiment institute of Vereinigte Stahlwerke, A. G. on experimental heat treating of steels of various carbon contents; hammer scaling and other factors influencing decarbonization, forms of decarbonization and its theory.

ETCH TESTS. Deep Etch Test For Iron and Steel, H. G. Keshian. Am. Soc. Steel Treat.—Trans., vol. 12, no. 5, Nov. 1927, pp. 689-727 and (discussion) 727-736, 30 figs. Describes types of structure revealed by method; factors influencing results, such as method of melting, chemical composition, reduction of area, heat treatment, direction of fiber in steel, etc.; points out value and limitations of method based on relation of various etch structures to performance of steel in service as observed by author.

GRAIN GROWTH. On Grain Growth in Mild Steels, Y. Chu-Phay. Am. Soc. Steel Treat.—Trans., vol. 12, no. 4, Oct. 1927,

pp. 601-621 and 688, 18 figs. Presents new data on grain growth of ferrite in mild steels (containing about 0.10 per cent carbon) upon annealing; nature and possible cause of differences from results of previous investigations; writer proposes theory of grain growth in mild steels, based on hypotheses that a boundary film exists, in which carbide is colloiddally dispersed, and discusses relation of boundary film to structural changes in steel upon annealing; slight age hardening in steel under investigation is noted and discussed.

HIGH TEMPERATURES, EFFECT OF. The Properties of Steel at High Super-Heat Temperatures, A. McCance. Liverpool Eng. Soc.—Trans., vol. 48, 1927, pp. 205-224 and (discussion) 225-240, 11 figs. Examination of temperature-strength curves for various steels; secondary effects of prolonged high temperature.

NON-METALLIC ENCLOSURES. Non-Metallic Enclosures. Metallurgist (Supp. to Engr.), Oct. 28, 1927, pp. 146-147. Points out that while doubt exists as to degree of harmfulness of these enclosures in regard to many of uses of steel, it is certain that they can and do involve harm in number of instances.

NORMAL AND ABNORMAL. Normal and Abnormal Steels. Am. Soc. for Steel Treat.—Trans., vol. 12, no. 3, Sept. 1927, pp. 413-435 and 478, 45 figs. Discussion of papers by J. D. Gat, and by S. Epstein and H. S. Rawdon, on normal and abnormal steel; includes results of investigation conducted to show that structural abnormality is not inherent and can be introduced by selective straining.

Progress in Study of Normal and Abnormal Steel, S. Epstein and H. S. Rawdon. Am. Soc. for Steel Treat.—Trans., vol. 12, no. 3, Sept. 1927, pp. 337-375, 21 figs. Normal and abnormal steel defined and characteristics of normal and abnormal structure in carburizing steel and tool steel illustrated; shows that under certain quenching conditions abnormal steel is more prone to give soft spots than normal steel, but that with drastic quenching in brine or in a sodium hydroxide solution, it is possible to completely prevent formation of soft spots in both normal and abnormal steel; normality and abnormality have origin in deoxidation procedure of steel making; additions of aluminum and ferrovanadium in mold produced abnormality.

NORMALITY. Normality of Steel, J. D. Gat. Am. Soc. for Steel Treat.—Trans., vol. 12, no. 3, Sept. 1927, pp. 376-413, 28 figs. Paper written to bring better understanding of term "normality of steel" and properties possessed by steels classified as abnormal; experiments to demonstrate behavior of steels having different grain size and amounts of segregated cementite; properties of "cementitic lining" present in abnormal steels; concludes that resistance to uniform hardening is caused by high oxygen content forming a eutectoid alloy with the constituents of austenite.

OXYGEN, EFFECT OF. Effect of Oxygen on Properties of Steel (Der Einfluss des Sauerstoffs auf die Eigenschaften des Stahles), W. Eilender and W. Oertel. Stahl u. Eisen, vol. 47, no. 38, Sept. 22, 1927, pp. 1558-1561, 9 figs. Summary of experimental studies on quantitative relation between oxygen content and mechanical and

electrical properties of ball-bearing steels, tungsten, natural steel, trans.

PROPERTIES.

Steels, J. E. How.—Trans., vol. 12, pp. 629 and 650. Properties of steel different condition are Poisson's ratio, limit, elongation, modulus of elasticity.

TEMPERATURE

Temperature of Microscopic Pro. Priester and O. Treat.—Trans., pp. 436-445, 12. tained on steel at carbon steel at Fahr. (600 deg. as hardened, 1112 deg. Fahr. tested at room strength tests v. peratures; tests hardness and in.

TEMPERATURE

in Mechanical Alloys with 7 propriétés méca avec la tempé Matte. Revue 4, Apr., 1927, translated abstr. Engineer), Sept. thors give co work on effect properties of st own experiment

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STEEL CAST

DEFECTS.

Steel Castings gen bei de nchtsilzierten tralblatt der no. 37, Sept. Descriptions remedies such and aluminum

STEEL, H

ANNEALIN

Machining P World, vol. 729-730. reating high

electrical properties of special steels such as ball-bearing steel, steel for cutting instruments, tungsten steel, chrome-nickel structural steel, transformer steel, etc.

PROPERTIES. On the Properties of Steels, J. E. Howard. *Am. Soc. Steel Treat.—Trans.*, vol. 12, no. 4, Oct. 1927, pp. 622-629 and 650. Discusses various physical properties of steel and their behavior under different conditions; some of points discussed are Poisson's ratio, Hooke's law, elastic limit, elongation and contraction of area, modulus of elasticity, coefficients of expansion.

TEMPERATURE, EFFECT OF. Effect of Temperature on the Mechanical and Microscopic Properties of Steel, G. C. Priester and O. E. Harder. *Am. Soc. Steel Treat.—Trans.*, vol. 12, no. 3, Sept. 1927, pp. 436-445, 12 figs. Describes results obtained on tests of a quenched 0.29 per cent carbon steel at temperatures up to 1112 deg. Fahr. (600 deg. Cent.) and on same steel as hardened, tempered at temperatures up to 1112 deg. Fahr. (600 deg. Cent.) and then tested at room temperature; only tensile strength tests were made at elevated temperatures; tests at room temperature include hardness and impact toughness.

TEMPERATURE, EFFECT OF. Variation in Mechanical Properties of Steel and Its Alloys with Temperature (Variations des propriétés mécaniques des aciers et alliages avec la température), A. Michel and M. Matte. *Revue de Métallurgie*, vol. 24, no. 4, Apr., 1927, pp. 200-209, 2 figs.; and translated abstract in *Metallurgist (Supp. to Engineer)*, Sept. 30, 1927, pp. 133-135. Authors give comprehensive review of past work on effect of temperature on mechanical properties of steel, as well as results of their own experiments.

TEXTURE AND STRENGTH. Effect of Texture on Strength Properties of Steels, with Particular Reference to the Notched-Bar Test (Ueber die Einwirkung der Korngrösse auf die Festigkeitseigenschaften von Stählen unter besonderer Berücksichtigung der Kerbschlagprobe), H. Hanemann and R. Hinzmann. *Stahl u. Eisen*, vol. 47, no. 40, Oct. 6, 1927, pp. 1651-1661, 14 figs. Tests of carbon steel and treated chrome-nickel steel show tensile strength and hardness practically uninfluenced by texture, while on other hand, impact strength of notched pieces increases with fineness; analysis of impact tests and strain areas developed, introducing new original concepts and terms.

STEEL CASTINGS

DEFECTS. Defects in Mild Non-Siliceous Steel Castings (Ueber einige Fehlererscheinungen bei der Herstellung von weichem, nichtsilizierten Stahl), K. Kerpely. *Centralblatt der Hütten u. Walzwerke*, vol. 31, no. 37, Sept. 14, 1927, pp. 517-520, 5 figs. Descriptions of usually observed flaws; remedies such as adding alloys of titanium and aluminum, etc.

STEEL, HEAT TREATMENT OF

ANNEALING. Electric Annealing Solves Machining Problem at Timken Plant. *Elec. World*, vol. 90, no. 15, Oct. 8, 1927, pp. 729-730. Exact requirements in heat treating high-carbon, high chromium steel;

850-kw. pit-type electric furnace anneals 84-ton charge of steel bars.

BALL-BEARING STEELS. Heat Treatment of Two Ball Bearings Steels. B. Kjerrman. *Am. Soc. Steel Treat.—Trans.*, vol. 12, no. 5, Nov. 1927, pp. 759-777, 8 figs. Results of electric-resistance tests on two steels, one of common type, other with higher content of chromium and addition of molybdenum; by resistance measurements on water-quenched test specimens, it is shown that it is possible to determine quantity of alloying elements which are effective in hardening a given steel; per cent hardening efficiency may be lowered by addition of too great quantity of alloying elements; this testing method should then afford means of determining cheapest analysis for steel of definite mechanical properties with definite hardening methods.

BOLTS. Low-Carbon Bolts Show Uniformly High Strength, E. F. Ross. *Iron Trade Rev.*, vol. 81, no. 17, Oct. 27, 1927, pp. 1025-1027, 2 figs. That tensile strengths of low-carbon steel, containing up to 0.15 per cent carbon, could be increased 30 per cent simply by making an extremely rapid quench was discovery of Roy H. Smith of Lamson & Sessions Co. at Kent, O.; numerous improvements which have been made during past two years are described.

COLD ROLLING. The Influence of Cold-Rolling and Subsequent Annealing on the Hardness of Mild Steel, C. A. Edwards and K. Kuwada. *Iron & Coal Trades Rev.*, vol. 115, no. 3109, Sept. 30, 1927, pp. 496-498, 15 figs. Object of experiments was to determine influence of varying degrees of cold work, in form of cold rolling, in direction of increasing hardness of mild steel, and temperatures at which this additional hardness is removed.

DESIGN PROBLEMS. Design From The Heat Treating Standpoint, G. M. Eaton. *Am. Soc. Steel Treat.—Trans.*, vol. 12, no. 5, Nov. 1927, pp. 794-811 and (discussion) 811-813, 7 figs. Author stresses need for closer co-operation between metallurgists and mechanical engineer; gives some typical problems still unsolved because of lack of union; freight-car bolster spring is discussed, and suggestions offered for possible elimination of it.

HIGH-SPEED STEEL. Production Heat-Treatment of High-Speed Steel, E. N. Brookings. *Am. Mach.*, vol. 67, no. 17, Oct. 27, 1927, pp. 641-643, 3 figs. Process of heat treatment that insures as far as possible a uniform quality product, and at same time allows for quantity production.

PRINCIPLES. Facts and Principles Concerning Steel and Heat Treatment, H. B. Knowlton. *Am. Soc. Steel Treat.—Trans.*, vol. 12, no. 3, Sept. 1927, pp. 479-491, 3 figs. Use of vanadium in various types of steel; heat treatments, properties and uses of the different types of steel.

QUENCHING. Quenching: A Practical Study on Rapid Cooling, P. J. Haler. *Mech. Eng.*, vol. 49, no. 11, Nov. 1927, pp. 1187-1191, 12 figs. Common methods of quenching; speed of plunging; influence of direction of plunging on distortion produced; flat-plate plunging experiments; solid and hollow cylinders plunged vertically, etc.

RAILWAY-SHOP TOOLS. Heat Treating Methods and Equipment Recommended for Railroad Shops. Ry. Jl., vol. 33, no. 10, Oct. 1927, pp. 21-23. Report of Committee of Am. Ry. Tool Foremen's Assn. on handling of railway repair tools requiring heat treatment; manufacture of and repairs to chisels, caulking tools, etc., high-speed machine tools, and reamers, taps, rivet sets, etc.

RATE OF HEATING. Heat Treatment and Metallography of Steel. H. C. Knerr. Forging-Stamping-Heat Treating, vol. 13, no. 10, Oct. 1927, pp. 420-422, 5 figs. Rate of heating.

THEORY. The Constitution of Steel and Cast Iron. F. T. Sisco. Am. Soc. Steel Treat.—Trans., vol. 12, no. 4, Oct. 1927, pp. 651-666, 10 figs. Study of theory of heat treatment; review of constitution of steel and cast iron from standpoint of stable equilibrium; solid solution of carbon in gamma iron, or austenite; discussion of grain growth of austenite above critical range.

STEEL, HIGH SPEED

TESTS. Comparisons of Impact and Slow Bend Tests of High Speed Steel. R. K. Barry. Am. Soc. Steel Treat.—Trans., vol. 12, no. 4, Oct. 1927, pp. 630-634, 1 fig. Results of tests show that high speed steel is harder after tempering at 1100 deg. than when tempered at 900 deg. Fahr., it will therefore have a higher tensile strength and higher transverse breaking strength with maximum deflection which would tend to increase brittleness and to decrease deflection under slow bend; high-speed steel tempered at 900 deg. is tougher or more ductile than when tempered at 1100 deg. which was indicated by impact test.

STEEL INDUSTRY

CLEVELAND-DETROIT EXHIBITS. Cleveland Machine-Tool Session. Soc. Automotive Engrs.—Jl., vol. 21, no. 4, Oct. 1927, pp. 333-341 and 444. Review of National Steel Week program and exhibits in Cleveland and Detroit.

STEEL MANUFACTURE

GROWTH OF. More Countries Now Making Steel. P. M. Tyler. Iron Age, vol. 120, no. 15, Oct. 13, 1927, pp. 1008-1011. Reduction in overseas shipments and sharpening of export competition; home demand growing in United States and Europe.

INGOTS MOLDS. New Valley Plant Uses Direct Metal for Ingot Molds. J. D. Knox. Iron Trade Rev., vol. 81, no. 17, Oct. 27, pp. 844-846, 3 figs. New plant of Valley Mould & Iron Corp., Hubbard, Ohio, designed essentially for production of ingot molds and stools.

ROCK DRILL. How Rock-Drill Steel is Made in Sweden. H. S. Brainerd. Compressed Air Mag., vol. 32, no. 10, Oct. 1927, pp. 2189-2192, 10 figs. Purity of ore and skill in mill produce steel of surpassing excellence for Ingersoll-Rand Company.

STEEL WOOL

MANUFACTURE. Do You Know How Steel Wool is Made? J. K. Williams. Machy. (N. Y.), vol. 34, no. 3, Nov. 1927, pp. 176-177, 1 fig. Several thousand steel strands

are cut simultaneously from small wire by almost 600 tools.

STEEL WORKS

POWER APPLICATION. Power Application in Steel Plant. Elec. World, vol. 30, no. 18, Oct. 29, 1927, pp. 877-882, 9 figs. New merchant mills in Gary works of the Illinois Steel Co. exemplify modern practice; highly developed methods speed production and improve quality of product.

STRUCTURAL STEEL

AIRPORT EQUIPMENT. Steel in Airport Development. Iron Age, vol. 120, no. 17, Oct. 27, 1927, pp. 1143-1145, 3 figs. Building frames and hangar sides and roof are recommended of steel.

WELDING

AIRCRAFT CONSTRUCTION. Welding the Aircraft Structure. J. B. Johnson. Am. Welding Soc.—Jl., vol. 6, no. 9, Sept. 1927, pp. 102-114, 13 figs. Advance in welding for construction of various units of airplane structure; materials used and their weldability; tests of welded structures.

ALUMINUM SHEET. Welding Pure Aluminum Sheet. Automotive Mfr., vol. 69, no. 6, Sept. 1927, pp. 17-19, 7 figs. Wide use of this material furnishes opportunities for fabricating special equipment; strength of welds; technique of work.

AUTOMOBILE PARTS. Welding of Automobile Parts. W. C. Happ. Am. Welding Soc.—Jl., vol. 6, no. 9, Sept. 1927, pp. 24-29. Explains in a general way what has been accomplished in the way of general welding practices at the South Bend Plants of Studebaker Corporation.

BRONZE. Describes Further Developments in Bronze Welding Cast Iron Pipe. H. Y. Carson. Foundry, vol. 55, no. 19, Oct. 1, 1927, pp. 763-764, 7 figs. Art of bronze welding cast iron has many useful applications for pipe; it simplifies and reduces cost of complicated fittings, and is being used more extensively for general repair work.

CAST IRON. Cast Iron Welding (Gusseisenschweissungen). O. Bardtke. Gieserei-Zeitung, vol. 24, no. 18, Sept. 15, 1927, pp. 505-515, 39 figs. Discussion reviewing methods of electrical and oxyacetylene welding as applied to iron castings, with many examples from practice.

CAST IRON. The Welding of Gray Cast Iron (Stand und Nutzen der Grauguss-schweissung). W. Zimm. Gieserei-Zeitung, vol. 24, no. 20, Oct. 15, 1927, pp. 561-566, 16 figs. Judging quality of cast-iron welds according to metallographic analysis; welding with and without preheating; electric cold welding with electrodes of special alloy castings have given best satisfaction.

HIGH-TEMPERATURE. Elevated Temperature Tests of Welds. K. V. Land and C. Moser. Am. Welding Soc.—Jl., vol. 6, no. 9, Sept. 1927, pp. 30-45, 18 figs. Preliminary report of tests conducted jointly by San Francisco Section of Am. Welding Soc., and Matis. Test. Lab., Leland Stanford Jr. Univ.; covers first two phases of investigation, assembly and proofing of equipment, and preliminary tests of number of specimens for the purpose of comparing various welding rods submitted.

MINUTES

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News of the Society

MINUTES OF THE MEETING OF THE BOARD OF DIRECTORS, SEPTEMBER 18, 1927

HOTEL STATLER, DETROIT

Officers Present: Messrs. J. F. Harper, F. G. Hughes, Dr. Zay Jeffries, W. H. Eisenman, R. G. Guthrie, L. D. Hawkrige, H. Bornstein, R. M. Bird.

Absent: J. H. Nead.

Upon motion by Mr. Hughes, seconded by Mr. Bornstein and unanimously carried, a communication from the Institute of Weights and Measures requesting the endorsement of the A. S. S. T. on their activities, was tabled.

Upon motion by Mr. Hughes, seconded by Mr. Bornstein and unanimously carried, the name of the exposition held by the Society was changed from the National Steel and Machine Tool Exposition, to be known in the future as the National Metal Exposition.

Upon motion by Mr. Eisenman, seconded by Mr. Hughes and unanimously carried, Messrs. R. M. Bird, W. B. Coleman and J. R. Adams of Philadelphia, were appointed to represent the Board of Directors of the Society to co-operate with the National headquarters in making arrangements for the 1928 Convention and Exposition.

Upon motion by Mr. Hughes, seconded by Mr. Bird and unanimously carried, a recommendation of the Publication Committee that all papers submitted for presentation at an annual meeting must be in the hands of the committee at least 90 days in advance of the date of presentation, to be preprinted; and that all papers intended for presentation at an annual meeting must be in the hands of the committee at least 60 days prior to the date of the Convention.

Upon motion by Dr. Jeffries, seconded by Mr. Eisenman and unanimously carried, the President and Secretary were charged with power to act to extend an invitation and make arrangements with the American Welding Society, and the Institute of Metals to join with the A. S. S. T. in National Metal Week in Philadelphia next year.

Upon motion by Mr. Bornstein, seconded by Mr. Hawkrige and unanimously carried, the President and Secretary were authorized to invite the American Gas Association through a communication to Major Forward, Secretary of the Organization, and Mr. T. V. Purell, chairman of the Industrial Gas Division of the A. G. A., to participate with the A. S. S. T. at Philadelphia, by installing another exhibit similar to the one held at Detroit.

Upon motion by Dr. Jeffries, seconded by Mr. Bornstein and unanimously carried, it was decided that the Educational Extension work being

carried on by Professor John F. Keller of Purdue University under the auspices of the A. S. S. T., should select a group of Western cities for the second series of lectures.

Upon motion by Mr. Hughes, seconded by Mr. Bornstein, the salary of J. Edward Donnellan was increased \$600.00 per year, effective September 1, 1927.

Upon motion by Mr. Bornstein, seconded by Mr. Guthrie, the salary of the Secretary was raised \$1000.00 per year, effective September 1, 1927.

Upon motion properly made, seconded and carried, the meeting adjourned.

Respectfully submitted, W. H. Eisenman, Secretary.

ENGINEERING EXTENSION LECTURES

DURING the past month five new engineering extension groups were organized by Professor John F. Keller under the sponsorship of the American Society for Steel Treating, Purdue University and the local chapters. The enrollment reached splendid figures, due to the fine work and enthusiastic support of these chapters.

The enrollments are as follows: Chicago 212, Milwaukee 212, Tri-City 132, Rockford 109, and South Chicago 181. Professor Keller states these are the largest lecture groups during his five years at this work. The enrollments exceeded by a great deal the expectations of the Board of Directors of the Society.

On the first of January, 1928, the present agreement between Professor Keller and the American Society for Steel Treating will expire and he will then return to Purdue University, where he will pursue the work which he has been doing for the last five years. This work is along identical lines with that which he has done with the Society, but is confined entirely to the State of Indiana.

While no official action has been taken as to seeking a renewal of the contract with Professor Keller a year hence, still it is probable that Professor Keller can be had for a similar series of lectures in the fall of 1928, providing there is sufficient interest manifested in this undertaking. At that time Professor Keller would be available, preferably, for a lecture group in some section of the country which he has not yet covered.

SEMI-ANNUAL MEETING

BY unanimous action of the Board of Directors it was decided some time ago to abandon two sectional meetings held by the American Society for Steel Treating during the winter months and in their place to hold one meeting, to be known as a Semi-Annual Meeting. In accordance with this action the first Semi-Annual Meeting of the Society will be held in Montreal, Thursday and Friday, February 16 and 17, 1928. The Semi-Annual Meeting will be preceded on Wednesday, the 15th, by a regular meeting of the Board of Directors of the Society and also a meeting of the Publication Committee and the Recommended Practice Committee.

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and members should make their reservations directly with the hotel as soon as possible, inasmuch as the winter sports will be in full session at that time, and Montreal as usual has a heavy hotel reservation during this period of the year. Consequently, it is urged that all members make their reservations at once.

The schedule for the meeting will probably include technical sessions morning and afternoon of Thursday, together with a dinner meeting Thursday evening, all of which will be preceded by the Early Birds' Dinner, which will be held on Wednesday evening. The Friday program will include technical sessions Friday morning with plant inspection or participation in winter sports on Friday afternoon, and the meeting will close with a technical session to be held Friday evening.

A splendid technical program has been arranged under the direction of William B. Coleman, chairman of the sub-committee on Meetings and Papers of the Publication Committee. Approximately 14 papers are to be prepared for presentation at the five technical sessions to be held during the Semi-Annual Meeting, the subjects and authors of which are as follows:

- Effects of Antimony, Arsenic, Copper and Tin in High Speed Tool Steel*—H. J. French and T. G. Digges, Bureau of Standards, Washington, D. C.
New Methods of Examining Structures—R. G. Guthrie, People's Gas Light and Coke Co., Chicago.
Spheroidizing—V. O. Homerberg, Massachusetts Institute of Technology, Cambridge, Mass.
High and Low Manganese in Steel—V. N. Krivobok, Carnegie Institute of Technology, Pittsburgh.
The Present Trend of Metallurgy—Dr. F. C. Langenberg, Climax Molybdenum Co., New York.
Alloy Steels in Boiler Construction—Charles McKnight, International Nickel Co., New York.
The Manufacture of Stainless Steel Castings in the Various Industries—V. T. Malcolm, Indian Orchard, Mass.
Metallurgy of Welding—S. W. Miller, Union Carbide and Carbon Research Laboratories, Long Island City, N. Y.
Cast Iron—B. F. Shepherd, Ingersoll-Rand Co., Phillipsburg, N. J.
Physical Properties and Structure, Longitudinally and Transversely, of Heat Treated Chromium-Molybdenum Sheet of Various Sizes—F. T. Sisco, Wright Field, Dayton, Ohio.
Medium Carbon Pearlitic Manganese Steels—Jerome Strauss, U. S. Navy Yard, Washington, D. C.

In addition to the authors and subjects listed here, papers are also to be presented by Messrs. W. J. Merten, Westinghouse Electric & Mfg. Co., East Pittsburgh; Fred H. Williams, Canadian National Railway, Montreal, Canada; and N. L. Mochel, Westinghouse Electric & Mfg. Co., Philadelphia.

Inasmuch as the Semi-Annual Meeting has national significance, not only from a high caliber of papers, but also from the number to be presented, the attendance will probably be much larger than at any of the previous sectional meetings.

REMOVAL NOTICE

AFTER December 1, 1927, the executive offices of the American Society for Steel Treating will be located at 7016 Euclid Avenue, Cleveland.

UNAUDITED PROFIT AND LOSS STATEMENT AMERICAN SOCIETY for STEEL TREATING

For the period from January 1 to September 30, 1927

INCOME

Gross Dues		\$40,003.16
Transactions Advertising	\$39,733.18	
Transactions Sales	1,020.11	
Transactions Subscriptions	1,299.18	42,052.47
General Index		465.00
Reprints		1,240.01
Bindery Account		931.99
Book Account		426.03
Miscellaneous Receipts		415.41
Data Sheets	2,078.23	
Data Sheet Binders	1,399.10	3,477.33
Discounts Received	517.90	
Interest	1,595.78	
H. M. Howe Medal Fund	61.98	2,175.66
Extension Division		3,425.00
Sustaining Exhibit Membership		6,800.00

EXPENSE

Local Chapters	\$17,431.30
Sectional Meetings	1,139.27
Extension Division	1,747.35
Transactions	27,383.05
Reprints	1,637.81
Bindery Account	1,389.95
General Index	925.01
Book Account	418.63
Library	136.22
Data Sheets	3,796.01
Data Sheet Binders	871.35
Discounts Allowed	465.05
General Expense	5,119.44
Collection & Legal Expense	227.38
Insurance	479.25
Miscellaneous Expense	17.03
Secretary's Office	12,205.92
President's Office	753.67
Treasurer's Office	3,465.40
Directors	2,321.89
National Committees	3,841.10

TOTAL EXPENSE \$85,772.08

EXCESS INCOME OVER EXPENSE..... \$15,639.98

BALANCE SHEET

As of September 30, 1927

ASSETS

Commercial Account	\$ 3,878.79
Savings Accounts	49,562.80
Accounts Receivable	17,900.51
Accrued Interest	100.69
Investments	82,846.25
Office Furniture & Fixtures	2,306.74
Inventory	4,129.95
1928 Convention Prepaid Expense	30.00
1927 Convention Prepaid Expense	54,575.07

TOTAL ASSETS \$215,330.80

LIABILITIES, RESERVES & SURPLUS

Accounts Payable	\$ 1,491.78
1927 Convention Advance Receipts	85,047.27
Reserves	35,515.05
Surplus—January 1, 1927	\$77,538.33
Plus—Credit Balance from Surplus Adjustment Account	96.95
Collection on Bad Accounts	1.44
Excess Income over Expense for the period from January 1 to September 30, 1927, per statement..	15,639.98

Present Surplus 93,276.70

TOTAL LIABILITIES, RESERVES & SURPLUS.... \$215,330.80

SCHEDULE

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News of the Chapters

SCHEDULED REGULAR MEETING NIGHTS OF CHAPTERS

For the convenience of visiting members, those chapters having regular meeting nights are listed below.

BOSTON—First Friday. H. E. Handy, secy., Saco-Lowell Shops, Lowell, Mass. Phone Lowell 4050.

- Dec. 2—Acid Open-Hearth, Crucible and Electric Furnace Practice, including some mention of Steel Castings.....G. B. Waterhouse
- Jan. 6—Testing MachinesI. H. Cowdrey
- Feb. 3—Methods of Constructing the Alloy Diagrams.....R. S. Williams
- Mar. 2—Hardening and Tempering of Steels.....R. S. Williams
- Apr. 6—PyrometryV. O. Homerberg
- May 4—Stainless Iron and Stainless Steel.....V. O. Homerberg

BUFFALO—Fourth Friday, with exception of Dec. 15 and Jan. 26. F. L. Weaver, secy., American Radiator Co. Phone, Riverside 1770.

CANTON-MASSILLON—No schedule of meetings as yet received. Robt. Sergeson, secy., Central Alloy Steel Corp., Canton, Ohio. Phone 5121.

CASE GROUP—No schedule of meetings as yet received. J. M. Burns, secy., Case School of Applied Science, Cleveland. Phone, Garfield 6680.

CHICAGO—Second Thursday, with exception of March 6. J. A. Comstock, secy., Room 1724 Peoples Gas Bldg. Phone, Wabash 6000, Local 364.

- Dec. 8—Specifying and Testing Automotive Steels.....R. H. McCarroll
- Jan. 12—Chromium PlatingH. E. Haring
- Feb. 9—Pyrometry and Its Application.....G. S. Gordon
- Mar. 6—Nickel Cast Iron.....P. D. Merica
- Apr. 12—Manufacture of Cold Drawn Steel.....F. R. Bonte

CINCINNATI—No schedule of meetings as yet received. W. J. Lange, secy., Robert J. Anderson, Inc.

CLEVELAND—Third Friday. J. S. Ayling, secy., Case Hardening Service Co. Phone, Atlantic 0293.

- Dec. 16—NitralloyH. A. DeFries
- Jan. 20—AircraftH. C. Knerr
- Feb. 17—Cap ScrewsTom Ferry
- Mar. 16—Brass and Bronze Alloy.....C. H. Bierbaum
- Apr. 20—Metal StampingG. L. Kelley
- May 18—Social Meeting.

COLUMBUS—Third Tuesday, with exception of Feb. 14. G. D. Moessner, secy., Buckeye Steel Castings Co. Phone, Garfield 0600.

- Dec. —Chemical Composition of Tool Steel and Effect of Alloying ElementsJ. P. Gill
- Jan. 17—Hardening of Steel and Effect of Size and Shape.....O. Z. Klopsch
- Feb. 14—Fuels and FurnacesH. J. N. Voltmann
- Mar. 20—High Speed Steels.....J. V. Emmons
- Apr. 17—ForgingsHarold Wood
- May 15—Open-Hearth PracticeW. R. Flemming

DAYTON—No schedule of meetings as yet received. F. M. Reiter, secy., Dayton Power & Light Co.

DETROIT—Third Monday. Jos. G. Gagnon, secy., Hudson Motor Car Co. Phone, Lenox 3232.

FORT WAYNE—No schedule of meetings as yet received. John A. Hansen, secy., S. F. Bowser & Co.

GOLDEN GATE—Second Wednesday. S. R. Thurston, secy., Bethlehem Shipbuilding Corp., San Francisco.

- Dec. 14—Annual Banquet
- Jan. 11—Heat Treatment of Ordnance Material.....Major T. J. Hayes
- Feb. 8—Stanford University Visit
The Relation Between Cutting Power of Metals and Their Heat TreatmentA. B. Domonoske
History of the Development of the Use of Metals.....T. J. Hoover

- Mar. 14—Symposium and Discussion by Members on The Physical Properties of Steel. Their Significance and Their Relations. Bases for the Selection of Carbon and Alloy Structural Steels for Special Purposes.
- Apr. 11—Joint Meeting with the American Welding Society—Subjects: Properties of Welds at High Temperature.....K. V. Laird
Properties of Carbon and Alloy Steels at High Temperatures.
- May 9—The Hardness of Metals, methods of testing and what they test. Comparison of the Wear Resistance of Different Metals under different conditions of Heat Treatment.
- June 13—Heat Treatments of Nonferrous Alloys, their purpose and their Significance.
Moving Picture—The Story of Copper.
- HARTFORD**—Second Tuesday. Henry I. Moore, secy., Firth Sterling Steel Co. Phone, 6-5554 Hartford.
- Dec. 13—Chromium PlatingDr. Wm. Blum
Jan. 10—New Developments in Stainless Steels at Home and Abroad....G. J. Comstock
Feb. 14—Ask Me Another—Speakers, Anyone with a Question.
Mar. 13—Heat Treatment of Aluminum Alloys.....R. S. Archer
Apr. 10—Manufacture of Automotive Alloy Steels.....E. C. Smith
May 8—Manufacture of Malleable Iron.....H. A. Schwartz
June 8—Eighth Annual Banquet.
- INDIANAPOLIS**—Second Monday. James S. Marlowe, secy., 606 State Life Bldg. Phone Riley 3724.
- LEHIGH VALLEY**—No schedule of meetings as yet received. H. V. Apgar, secy., Ingersoll-Rand Co., Phillipsburg, N. J. Phone 977.
- LOS ANGELES**—No schedule of meetings as yet received. H. V. Ruth, secy., Ducommun Corp.
- MILWAUKEE**—No schedule of meetings as yet received. Knight Charlton, secy., Bucyrus Co.
- MONTREAL**—No schedule of meetings as yet received. D. G. MacInnes, secy., Apt. 35, 376 Claremont Ave., Westmount, Montreal.
- NEW HAVEN**—Second Thursday, with exception of December 15. F. E. Stockwell, secy., Standard Oil Co. of New York. Phone, Beacon 1520.
- NEW YORK**—Second Monday. I. N. Holden, Jr., secy., E. W. Bliss Co. Phone, Sunset 9000.
- NORTH-WEST**—No schedule of meetings as yet received. Alexis Caswell, secy., Manufacturers' Assn. of Minneapolis.
- Dec. —Carburizing and Carburizing Compounds.....H. B. Knowlton
Jan. —Gas and Gas Carburizing.....R. G. Guthrie
Feb. —Nitralloy.....R. P. DeVries
Mar. —Open
Apr. —Molybdenum Steels.....Dr. F. C. Langenberg
May —Gears and Gear Steel.....E. C. Smith
- NOTRE DAME**—Second Friday, with exception of December 8. Frank J. Mootz, secy., Notre Dame University. Phone, Lincoln 1121.
- PHILADELPHIA**—Last Friday, with exception of December 9 and January 6. A. W. F. Green, secy., 407 Shoemaker Rd., Elkins Park, Pa. Phone, Melrose 4542-M.
- PITTSBURGH**—No schedule of meetings as yet received. H. L. Walker, secy., Box 521, North Side Station.
- RHODE ISLAND**—Third Wednesday. C. G. Peterson, secy., 100 Weybosset St., Providence. Phone, Gaspee 6233.
- ROCHESTER**—Second Monday. Irving C. Mathews, secy., Eastman Kodak Co. Phone, Glenwood 1300.
- Dec. 12—Sheet Steel Stampings.....G. H. Kelley
Jan. 9—Malleable IronEnrique Touceda
Feb. 13—TestingT. Y. Olsen
Mar. 12—Dr. Jekyl and Mr. Hyde of Metallurgy.....T. S. Fuller
Apr. 9—Die CastingsSam Tour
May 14—Business Meeting—Election of Officers
- ROCKFORD**—Second Friday, with exception of Jan. 12. O. T. Muehlemeyer, secy., 700-702 Race St. Phone, Forest 447.
- SCHENECTADY**—Third Tuesday. J. G. Hicks, secy., American Locomotive Co. Phone, 2-4900-Ext 44.
- Dec. 20—Machinability.....A. H. d'Arcambal

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- Jan. 17—Magnetic Analysis, Particularly as Applied to High Speed and other Steels.....A. V. deForest
 Feb. 21—Machinability and Machining Problems of Nickel Steels and Ordinary Cast Iron, Monel Metal, etc.....T. H. Wickenden
 Mar. 20—Steels at Elevated Temperatures.....H. J. French, F. B. Foley

SOUTHERN TIER—Third Monday, with exception of Nov. 28 and Apr. 23. Walter H. Ogden, secy., 11 Rotary Ave., Binghamton, N. Y. Phone, Bingham 2425.

SPRINGFIELD—Third Monday, with exception of Mar. 21, Apr. 25 and May 23. E. L. Woods, secy., Springfield Gas Light Co. Phone, 5-3900.

ST. LOUIS—Third Friday. C. G. Werscheid, secy., Colonial Steel Co. Phone, Garfield 1263.

SYRACUSE—See page 1018 for schedule for year. S. P. Peskowitz, secy., Halcomb Steel Co.

TORONTO—No schedule of meetings as yet received. Campbell Bradshaw, secy., 153 University Ave.

TRI CITY—No schedule of meetings as yet received. George A. Uhlmeier, secy., People's Power Co., Moline, Ill.

WASHINGTON-BALTIMORE—No schedule of meetings as yet received. H. K. Herschman, secy., Bureau of Standards.

WORCESTER—Dec. 9, Jan. 6, Feb. 3 and Mar. 14—no further meeting dates as yet scheduled. C. G. Johnson, secy., Worcester Polytechnic Institute. Phone, P110.

STANDING OF THE CHAPTERS

DURING the month of October there were 110 new and reinstated members, while 37 were lost through arrears, resignations and deaths, leaving a net gain for the month of 73 members. The total membership of the Society on November 1, 1927, was 4809.

Membership standing of the society as of November 1, 1927 is as follows:

GROUP I		GROUP II		GROUP III	
1. Detroit	507	1. Dayton	136	1. Tri-City	86
2. Chicago	421	2. Hartford	129	2. Los Angeles	84
3. Pittsburgh	343	3. Milwaukee	126	3. New Haven	83
4. Philadelphia	325	4. Lehigh Valley	116	4. Worcester	73
5. Cleveland	315	5. Canton-Mass.	112	5. Washington	71
6. New York	296	6. Golden Gate	108	6. Southern Tier	63
7. Boston	249	7. Indianapolis	97	7. Rochester	63
		8. Cincinnati	91	8. Rockford	62
		9. St. Louis	90	9. Columbus	57
		10. Syracuse	86	10. Toronto	57
		11. Montreal	69	11. Providence	54
		12. Buffalo	67	12. Fort Wayne	41
		13. North-West	52	13. Schenectady	40
				14. Springfield	35
				15. Notre Dame	25

BOSTON CHAPTER

The November meeting of the Boston Chapter was held at Massachusetts Institute of Technology, Cambridge, on Friday, November 4, 1927. Dinner was served, as usual, in Walker Memorial at 6:30 p. m. to about seventy members and friends.

The speaker of the evening was R. F. Harrington, metallurgist, Hunt-Spiller Mfg. Corporation, Boston, whose subject was "Technical Control in the Modern Iron Foundry". Mr. Harrington has long been identified with the manufacture of high grade gray iron castings for automotive and locomotive parts, and has made an extensive study of the metallurgy of cast iron and of fuels and molding sand. He is a past president of the New England Foundrymen's Association and is chairman of the Committee for Molding Sand Conservation and Reclamation of the American Foundrymen's Association.

He began his talk by stating that to satisfy the demands of the consumer today, gray iron must be of a better quality than ever before and that only by realizing this fact and getting busy can the foundryman stop the present substitution of forgings, steel and malleable castings and built-up welded parts for those parts formerly made of cast iron. Where a few years ago a gray iron of 30,000 pounds tensile strength was considered high test, 50,000 is now demanded and in some cases Charpy, Izod and even shear tests are mentioned in the customers specifications. To cope with this situation it is necessary first to subject the raw materials to a very rigid inspection. Pig iron cars, as they are received, must be uniform and contain only one grade of iron, not several grades which when drilled and made up into a composite sample will show the required analysis. Scrap must be selected carefully and the fuel, whether coal or coke, must be purchased to specification and tested before it is used.

The question of molding sands is a very important one, according to the speaker, fully 50% of the foundry rejections in most shops being due to sand troubles. The moisture must be of the right percentage for the particular job, the sand must contain enough clay bond to give it the required strength and it must have a permeability great enough to allow the escape of the gas formed when the metal is poured into the mold. The foundry, with which the speaker is connected, goes still farther and actually measures the hardness of the mold itself and also its permeability. By this method of control the losses due to sand troubles have been greatly reduced.

Mr. Harrington explained the working of the air furnaces in which the iron is melted. Powdered coal is used for fuel and since this method of melting was adopted a better iron is obtained with absolute time and temperature control, and with greater economy of furnace refractories. The heats are under optical pyrometer control at all times and it has been proven that each particular type of casting has its own correct pouring temperature. He touched lightly on the reclamation of molding sand, stating that whereas formerly great quantities of new molding sand were added to the heaps daily, the present additions consist only of a mixture of some four parts of Cape Cod beach sand of the proper grain size, and one part of a special bonding clay. Large savings have been made but to accomplish these results a great amount of laboratory supervision has been necessary, some 12 men being constantly engaged in control work. He concluded his talk by advising that research and economy be based on better castings and not, primarily, to produce cheaper ones. An interesting discussion followed. The attendance was 120.

H. E. Handy.

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BUFFALO CHAPTER

The October meeting of the Buffalo Chapter of the American Society for Steel Treating was held on the evening of the 27th and was called to order by Chairman B. L. McCarthy at 8:30 p. m.

The first speaker J. F. Williams, Federal Chemist, Bureau of Internal Revenue, gave an interesting talk on the history and manufacture of alcohol and the analysis of today's unlawful beverages and narcotics.

The principal speaker, S. C. Spalding, metallurgist, Halecomb Steel Company whose subject "Carburizing" was very complete and unusually interesting being accompanied by slides showing the effects on various types of steel. An interesting discussion followed.

About 50 members and guests were present, lunch being served after adjournment.

F. Weaver.

COLUMBUS CHAPTER

The Columbus Chapter held its first meeting of the fall, Tuesday evening, October 18, 1927, at the Fort Hayes Hotel. The meeting was attended by 100 members and guests and was preceded by a dinner at 6:30 p. m.

After a few announcements were made by our chairman G. S. McFarland, he introduced the speaker of the evening, Jordan Korp of The Leeds & Northrup Co. of Philadelphia. Mr. Korp gave a practical talk on Heat Treatment and Its Relation to Production. During the talk Mr. Korp used the blackboard very effectively to illustrate points under discussion. A brief outline of this talk follows.

Mr. Korp started his talk by relating the marked difference between information given the designer and tool maker as compared to information given the hardener. As a general rule the tool maker has all the information to work with in order to make a perfect tool. In fact, if a dimension is missing, it is quickly furnished. All this information gives the tool maker every opportunity to make a perfect tool, then this perfect tool is sent to the hardener and about all the information that goes with it is, here is a tool and we want it right away. The hardener who has as many variables as the tool maker to deal with, treats the tool with this meager information and many times results disastrously.

The hardening of steel successfully requires that strict attention be paid to details. Mr. Korp then stressed the following points, the rate of heating; the rate of cooling; the volume of quenching medium; the temperature of the quenching medium; the tempering temperature, and the time of tempering.

In concluding Mr. Korp said the hardener gets a hundred per cent of the blame when a tool fails, and failure occurs when a tool is not everlasting. But it has been proven that the hardener is not always to blame, for the designer and tool maker come in for their share of the blame and if we want to get the best results we must control all conditions.

Mr. Korp's paper was very well received by all those present, and we wish to express our appreciation to Mr. Korp for his splendid paper.

G. D. Moessner.

DAYTON CHAPTER

The October meeting of the Dayton Chapter was held Monday evening, October 24th, at the Engineer's Club. An excellent dinner was enjoyed by forty members and their friends. The coffee talk was given by Lt. J. A. Macready, former chief of the Flying Section, Army Air Corps, Wright Field. Lt. Macready's subject was "Long Distance Flying." He discussed some of the problems and dangers encountered in making long distance flights and stressed particularly the long and arduous preparations necessary to insure that the flight will be successful. There is no one better qualified to talk on this subject than Lt. Macready, who for several years held the world's altitude record and who was one of the pilots on the first coast to coast non-stop flight.

The educational feature preceding the talk of the evening was an elementary illustrated discussion of the metallographic constituent "Cementite," and was given by L. H. Grenell, metallurgist for Delco Light Co. The principal talk of the evening was given by J. P. Gill, metallurgist of the Vanadium Alloys Steel Co. Mr. Gill discussed "The Effect of the Alloys Used in Tool Steel." Mr. Gill gave an exceptionally interesting talk which was principally along the lines of the effect of the various alloying elements, nickel, chromium, tungsten, manganese, silicon, molybdenum, vanadium and uranium on tool steel. He compared the analysis and properties of the various tool steels and emphasized the effect of minute quantities of impurities on the material. Special attention was given by the speaker to high speed and oil hardening steels and their composition.

The November meeting of the Dayton Chapter will be a nonferrous session.

F. T. Sisco.

FORT WAYNE GROUP

The October meeting of the Fort Wayne Group was held on Thursday, October 13, 1927, at the Y. M. C. A. The meeting was preceded by a dinner at which H. B. Knowlton, vice chairman, acted as toastmaster in the absence of the chairman, W. E. McGahey.

The International Orchestra entertained during the dinner, which was attended by fifty members and guests. After the dinner, the speaker, J. A. Succop, chief of research of the Heppenstall Forge and Knife Co. of Pittsburgh, was introduced by Mr. Knowlton. Mr. Succop illustrated his talk "The Story of the Die Block" with moving pictures.

The speaker brought out very clearly, the various steps in the making of a die block from the time the steel was refined in the open-hearth furnace, through the various steps under the large hydraulic squeezer where the ingot was handled entirely by the mechanical manipulator down through the finishing steps to the grinding and marking of each die block before shipment.

A very important point in the making of a die block was brought out by the speaker, the upsetting process which changes the grain structure and does away with fibrous material, which is very important, as a die block should be equally strong in all directions which is not true of fibrous material.

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After a lengthy discussion which brought out questions not only in connection with forging, chemical compositions, but also grinding problems, the meeting was adjourned at 10:30 p. m.

Out of town guests present were G. O. DeSautels, Indiana's representative of the Heppenstall Company and Mr. Thomas Thomas, Indiana's representative of the Cleveland Twist Drill Company and a member of the Cleveland Chapter.

We were also honored by the presence of former secretary of the Fort Wayne Group, A. L. Cramp, of the G. O. DeSautels Company of Indianapolis.

J. A. Hensen.

GOLDEN GATE CHAPTER

The Golden Gate Chapter held its monthly meeting for October, Monday evening the 10th, at the new quarters of the Engineer's Club, on the fourteenth and fifteenth floors of the Insurance Center Building. It was necessary to hold the meeting Monday instead of Wednesday, which is our regular meeting night, in order to take advantage of the limited visit of the speaker of the evening.

After enjoying a splendid dinner of which thirty-seven participated, which was increased to about fifty after the dinner, and admiring the pleasant surroundings, the meeting was called to order by Mr. S. C. Alexander, vice chairman, by using the A. S. S. T. bell. Mr. Alexander called upon Mr. P. Mapes for an explanation as to how Golden Gate Chapter came in possession of the bell.

We were then informed by Mr. Alexander that Mr. P. Mapes had received a letter from W. H. Eisenman, National Secretary, which, due to the absence of our secretary S. Thurston, was read by F. E. Peterson. The letter was for the purpose of ascertaining the possibilities of having a National Metal Exposition on the Pacific Coast. A committee was appointed by our chairman for the purpose of investigating and reporting on the question.

E. E. Fess was next called upon to answer the question, "What approximate percentage of chromium is required in a steel to materially resist heat effects at 1200 degrees Fahr.—at 1600 degrees Fahr.—at 1800 degrees Fahr.?" Roy T. Wise next discussed the relative merits of carbon and alloy steels for die blocks and for dies of intricate design. These questions were ably answered and will no doubt be of benefit to many who were present.

Owen K. Parmiter, metallurgical engineer of the Firth-Sterling Steel Company, the speaker of the evening, addressed the chapter on "New Developments in Stainless and Alloy Steels." Mr. Parmiter gave a very splendid paper on the subject, bringing out many points that were no doubt new to many of us present.

After Mr. Parmiter had delivered his paper, the meeting was open to any one who had any questions to ask. Several took advantage of this opportunity after which the meeting was adjourned.

F. E. Peterson.

HARTFORD CHAPTER

The Hartford Chapter held its November meeting on Tuesday, November 11 in the Hartford Electric Light Auditorium. William Finkl, metallurgist of A. Finkl & Son, Chicago, delivered a talk on the "Heat Treatment of Alloy Steel Die Blocks". Mr. Finkl discussed the manufacture, selection of material, heat treating and inspection methods that enter into the production of alloy steel die blocks. The speaker used several reels of motion pictures to bring his explanations to the better attention of his listeners. These films were taken at the Finkl Plant in Chicago and covered all phases of the speaker's talk.

The discussion of his paper required about three quarters of an hour and brought out many local experiences with heat treated die blocks. The usual argument was again started regarding the method of tempering die blocks on a hot plate, and as yet neither side has satisfied the other in any way on this subject.

Following Mr. Finkl's talk the Hartford Chapter introduced an innovation which will probably be continued the rest of the year. A practical man gave a practical talk concerning his own work and described some difficulties which he had been encountering at his plant and described the method which was used in solving the problems. The talk was given by G. A. Zettersvall who is foreman of the heat treating department of the New Britain Machine Company, New Britain, Connecticut. The subject was "Certain Problems in Operating Carburizing Furnaces". In view of the success of this talk and the number of questions which were brought out it has been decided to continue talks of this nature along with the regular program at each future meeting. This is the first attempt of the Hartford Chapter to get the practical man on his feet and talk before the Chapter. Several other Foremen Heat Treaters in the Hartford district have consented to give a talk of this same nature at future meetings. The practical men have innumerable experiences and have devised many clever schemes in handling miscellaneous heat treating problems and it is felt that if these men will get up before the Chapter and "Talk Shop" in their own language, the purpose of this Society will be extended in the way that it is intended.

On November 12th Mr. W. H. Eisenman, national secretary, visited Hartford and had the executive committee meet with him in the evening along with vice president, F. G. Hughes, and past president Frank P. Gilligan.

R. Stanton.

NOTRE DAME GROUP

The Notre Dame Group held its initial meeting of the year on October 6, 1927, and was well attended by the members and guests.

Mr. Raymond Spencer, who will receive his Doctor's degree in metallurgy next June, reviewed the paper by Keller on "Why Metal Warps."

Mr. William Foohey, M. S. '26, reviewed the paper by Honda and Iwase on "The Transformation of Austenite into Martensite by Stress." After discussion of these papers by the members the meeting was adjourned.

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Dr. Neiuwland, well-known organic chemist and botanist, has taken an interest in metallurgy and has joined our Group. *Frank J. Mootz.*

The November meeting of the Notre Dame Group was held on November 11, 1927. Despite the inclement weather, the meeting was well attended.

Mr. Ernest Wilhelm, graduate student in chemistry, discussed the paper "Aircraft Metallurgy" which was presented at the Detroit Convention by Knerr.

Mr. Robert Bannon reviewed the article on "The Metal Manganese and its Properties" by Sir Robert Hadfield which appeared in Vol. CXV of the *Journal of the Iron and Steel Institute*.

After discussion of these papers by the members, refreshments were served. Mr. Bannon showed that he was not only a coming metallurgist but was a proficient card "shark" and entertained with a few of his mysterious tricks.

Mr. White, chief metallurgist of the Clark Equipment Co., Buchanan, Mich., and Mr. Wynn of the same company were at the meeting. Mr. Wynn, who is not a member of the Society, filled an application for membership.

Frank J. Mootz.

PHILADELPHIA CHAPTER

The Philadelphia Chapter held its regular monthly meeting for October at the Engineers' Club, of Friday evening the 28th. The dinner which preceded the meeting was well attended. The chapter is endeavoring to make the dinners more popular by having a ten-minute "coffee talk" just after the serving of the last course. These talks are to be given by persons outside of the scope of the Society and are intended to be entirely non-technical. There is hope that the "coffee talk" period for the November 18 meeting will be addressed by the Director of Public Safety of Philadelphia, Geo. W. Elliott.

The speaker for the October meeting was Dr. F. C. Langenberg, vice president of the Chlmax Molybdenum Co., whose topic was "The Trend of Metallurgy". This was treated in a very splendid manner by the speaker, and pertinent points emphasized with the use of lantern slides. The talk was quite educational and not too technical, so that the seventy-five or more listeners were able to follow the entire discourse intelligently. This fact was very evident from the discussion which the speaker's presentation provoked.

The Philadelphia Chapter announces the second annual Smoker at this time, which is to take place on December 9 at the Benjamin Franklin Hotel. Members of chapters outside of Philadelphia who may happen to be in the city or its vicinity about that time are most cordially invited to attend. Reservations may be made through the secretary of the chapter.

It may be of interest to know that the Course in Metallography and Heat Treatment which is given at Temple University under the auspices of the chapter has an enrollment in excess of sixty students, and that an additional lecture course is being made available for second year students and alumni.

Arthur W. Green,

PITTSBURGH CHAPTER

The November meeting of the Pittsburgh Chapter was held on the evening of the 3rd in the U. S. Bureau of Mines Building. A supper was served in the restaurant at 6:30 p. m., which was unusually well attended.

Starting at 7:30 two movies were shown in the auditorium; the first was, "Fifty Years of Telephone Progress" which showed the wonderful improvement and refinement of the telephone and its tremendous growth into a necessity of everyday life, and the second, "Pole Pushers of Puget Sound", illustrated a part of the logging industry.

At 8 o'clock, chairman James P. Gill called the meeting to order and proceeded with the business of the evening.

Having completed the chapter's business, chairman Gill introduced J. V. Emmons, metallurgist of the Cleveland Twist Drill Company, as the speaker of the evening who spoke on "Tool Hardening Problems with Special Reference to High Speed Steel".

Among the reasons given for the selection of high speed steel for cutting work were that higher cutting speeds were possible, that harder materials could be machined and that it would stand a higher operating heat.

Of the various types of high speed used, the 18% W, 4% Cr, 1% Va was the most popular and used in possibly 90 per cent of the work. The next most popular type was the 14% W, 4% Cr, 2% Va but it was considered more erratic in performance. Other alloy additions such as cobalt, molybdenum and uranium have been used but never have become popular.

After a type of steel has been determined upon, its inspection is quite important. In the case of large and well equipped plants a visible inspection is first given for mechanical defects such as seams, etc., a microscopic inspection for such defects as decarburized surface, carbide segregation, etc., then a chemical test and, finally, a hardening test. In the smaller shops, in addition to the visible inspection, the hardening test is very helpful.

In designing tools, difficulty will arise from the following causes: sharply designed angles, sharp corners, and heavy sections running into light sections. Deep stamping or marking and coarse machining originate cracks causing tool loss.

The semi-muffle furnace has proven to be the most popular type of hardening furnace though the electric furnace and salt bath are used also.

In heating for hardening, the preheating time is very important in respect to large tools and a tool of both light and heavy sections demands especial care. The atmosphere of the furnace should be carefully watched to protect the tool from scaling.

The quenching medium for hardening may be selected from the following: air, air blast, oil and heavy oil spray. Quenching high speed in water is very dangerous though if successful often gives a good tool. However, a good rule to follow is, "Keep hot high speed away from water even to cooling after grinding".

There are two ranges of temperature for tempering, namely; 350 to 600 degrees Fahr. and 1000 to 1200 degrees Fahr. but the temperature most generally used is 1100 degrees Fahr. After 1200 degrees Fahr. has been passed the toughness does not increase.

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Microphotographs were then shown which illustrated errors in hardening and what the correct structure should be.

During the general discussion which followed this talk, many questions were asked and opinions expressed bearing on the various phases of this subject which had been so ably handled by Mr. Emmons.

Harry A. Neeb Jr.

ROCKFORD CHAPTER

The second regular meeting of the Rockford Chapter was held Wednesday, November 9, in the Venetian Room at the Nelson Hotel. Dinner was served to sixty-two members preceeding the meeting.

Chairman Swan Hillman presided at the business meeting which opened at 8 p. m. Mr. Taveira, chairman of the Educational Committee, gave a report on the progress made toward completing the arrangements for Professor Keller's course of six lectures on "Steel and Its Heat Treatment," to be given in Rockford during the next six weeks. From all indications, there will be a large enrollment for Mr. Keller's course in Rockford.

The speaker of the evening was James P. Gill, Metallurgist for the Vanadium-Alloys Steel Company. Mr. Gill delivered a very interesting talk on "Tool Steels, Chemical Composition and the Effect of Alloys thereon."

Mr. Gill gave the characteristic properties imparted by various per cents of the alloying elements, chromium, manganese, silicon, nickel, vanadium, tungsten, molybdenum and cobalt. The talk was very well received, and it brought forth considerable interesting discussion. A rising vote of thanks was extended to Mr. Gill and the meeting adjourned at 10 p. m.

H. W. Gustafson.

SYRACUSE CHAPTER

The first meeting of the fiscal year was held in the Chamber of Commerce building and was informally opened with the usual get together dinner, attended by about eighteen of the members and guests. Chairman Frazer formally opened the meeting with pleas to the members to attend the dinners as well as the meetings more regularly and in general to lend their support to the chapter in order to improve its standing. The membership committee reported a net loss in total membership for the past year, although a considerable number of new memberships had been obtained. In order to stimulate a drive for new members, the chapter voted to award as a prize a 10-magnification inspection pocket glass to that member who had turned in the greatest number of memberships by the first of the year.

Following this, Mr. Richardson, publicity agent for the Bethlehem Steel Corporation, was introduced as the speaker of the evening. He presented as his topic a few of the widely known educational picture films, showing the manufacture of iron and steel in all its phases from beginning to end. Choosing those reels which would be of most interest to an audience in a tool steel city, he introduced his topic with scenes of Bessemer and open-hearth operation, showing the spectacular production of steel in large tonnages. The remaining reels dealt with the manufacture of tool and alloy steels in conjunction with the electric furnace. The difference in the

scale of operation between this and the previously shown structural steel manufacture was at once strikingly noticeable. The making of fine tool and alloy steels implies the careful processing, in small lots, of specially chosen ingredients, under skilled observation and chemical control. The films carried us on through the casting operation, the rolling of the ingots to blooms, then to bars and shapes and through to the final inspection. All through these final films our attention was directed to the great care exercised in every step of the process so necessary to produce sound and flawless tool and alloy steels.

Mr. McKenzie, chairman of the entertainment committee, presented for our approval a tentative list of speakers for the coming year, as follows:

November 8th—T. H. Nelson—"Comparison of European and American Methods of Steel Making." December 13th—J. B. Johnson—"Responsibility of Metallurgy to the Development of Aircraft." January 10th—T. H. Wickenden—"Automobile Design and Automotive Steels." February 14th—W. W. Macon—"Some Phases of the Iron and Steel Industries." March 13th—B. F. Shepherd—"Carburizing and Heat Treatment of Carburized Objects." April 10th—J. H. Nelson—"Flow of Metals in Forging."

S. Peskowitz.

TRI-CITY CHAPTER

On November 2nd Jordan Korp addressed 105 members of the Tri-City Chapter of the American Society for Steel Treating at Johnson's Cafeteria, Rock Island, on the subject of "Treatment of Steel Tools".

Mr. Korp pointed out the limitations of speed in heating up the materials due to the rate at which the material can absorb the heat. Non-uniform heating produces strains in the tool which will in all probability cause it to fail.

The distance the tool is heated either above or below its critical temperature determines the properties for which the tool is best adapted. After heating, the quenching operation must be standardized as to the volume of the quenching liquid, its temperature and its density and pressure. The rate of cooling during the quenching operation should be just as uniform as is the heating operation.

The tempering operation after quenching must likewise be standardized as to time and temperature. Experiment is the best means for establishing the best conditions of temperature and time of tempering. Mr. Korp suggests the following brine strengths and temperatures for best results in quenching.

7-10% salt solution at a temperature of 60-65 degrees Fahr.

10-12% salt solution at a temperature of 68-70 degrees Fahr.

12-15% salt solution at a temperature of 78-80 degrees Fahr.

Mr. Korp pointed out that in most instances about 46 per cent of tool failures can be attributed to faulty design and circumstances out of control of the heat treater, while 54 per cent of the failures are due to improper heat treating methods.

Following the dinner which preceded the talk, Mr. C. E. Oberlander gave several humorous readings.

G. A. Uhlmeier.

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WASHINGTON-BALTIMORE CHAPTER

The first meeting of the year was held on October 21st in the Auditorium of the New Interior Building. It was preceded by an informal dinner in honor of the speaker of the evening, C. E. MacQuigg, metallurgist, Union Carbide and Carbon Research Laboratories, which was well attended.

Mr. MacQuigg gave a very interesting talk on "Recent Developments and the Trend in Engineering Steels".

The increasing demand for ever more rapid transportation facilities and consequent demand for lighter and stronger material was first reviewed. This demand was being met by the increasing use of alloys in cast irons and steels.

A full discussion was given to alloy steels particularly the silicon, chromium and chromium-nickel steels. Reference was made to work of the Navy Department back in 1910 on silicon steels which seemed to have been lost sight of until 1922, when Burgess again called attention to the possible advantages of silicon as an alloying element in steel in addition to its more usual rôle of a deoxidizer. The more recent work in Germany was cited and detailed mechanical properties were given.

The recent use of a manganese-silicon steel of approximate composition 0.76 manganese, 0.27 silicon, 0.35 chromium in the Port Richmond Station power house and consequent advantages of lighter construction was brought out. These steels had also been studied some years ago but had been dormant until quite recently. Similar steels were being used in automobile construction and for rails. The necessity of keeping the carbon to manganese ratio low was emphasized. A simple heat treatment was better than a complicated one.

The chromium and chromium-nickel steels were also quite fully discussed with particular reference to their resistance to oxidation at higher temperatures. The principal point is to maintain the iron in the austenitic condition. About 20 per cent chromium was required to obtain oxidation resistance. For higher temperatures 25 per cent chromium and 8 per cent nickel was used.

The advantage of from 14 to 16 per cent of chromium in cast iron was also pointed out as making a relatively cheap heat resistant material.

Some of the speaker's investigations had shown a favorable relation of zirconium to manganese in steels particularly with reference to a marked increase in impact resistance. The possibilities of high chromium iron resistors were touched on briefly.

The talk was followed by a lively discussion showing special interest in the manganese silicon steels and also tended to confirm the speakers opinion that the trend was toward higher alloy lower carbon content steels for structural uses. It was pointed out that one of the difficulties of the high silicon steels was its relative lack of deep hardening characteristics. Another point which had been previously emphasized by the speaker was the advantage of combined hardness and toughness obtained in high alloy steels apparently giving greater abrasive resistance.

John R. Freeman, Jr.

WORCESTER CHAPTER

The third meeting of the Worcester Chapter was held at Rebboli's Restaurant in Worcester. There were about 60 members present and five guests. The meeting was opened by Mr. Bigelow, chairman of the Worcester Chapter, his most interesting announcement being that in a few months the membership of the Chapter has increased from 40 to 78 members.

The speaker of the evening, Robert S. Williams, Professor of Physical Metallurgy at the Massachusetts Institute of Technology, was then introduced. Mr. Williams, before entering on his subject "Application of Metallography to Industry", gave a preliminary description of the methods and materials usually employed in preparing specimens to be photographed.

The speaker divided his lecture into three parts and considered metallography first in its application to the selection and specification of materials. Second to the investigation of defective materials ascertaining the causes or failures and third to development and research work.

Under the first heading several instances were related showing a growing use of metallography in selection and specification of material, many concerns at the present time paying particular attention to the grain size of their raw material. Under the second heading, many instances of defective material were illustrated on the screen. The defects in the material were plainly shown, and an explanation was given for the cause of each failure. These pictures included bearing metal, babbitt composition, brass and bronzes, many of which were the result of studies conducted during the war in connection with shell work and also some very interesting photographs of copper wire conductors where inclusions of copper oxide which reduce the conductivity of the wire, were plainly shown. Under the third heading, that of development and research, a very interesting and instructive discussion of the work that is being done on nitrogen hardening under the Krupp patents was given by Mr. Williams. The experiments, however, have not reached a point, he said, where definite plans and figures could be advanced. The hardness attained, however, is greater than that obtained by the present means employed for hardening steel, by a very large amount. A further advantage in this method of hardening was found in the fact that the temperature of the work need not be above 900 degrees. All work is kept in the presence of ammonia gas and the depth of the case will depend upon the time. The development work is proceeding, and it is hoped that definite accomplishment along these lines may soon be attained.

He also described the X-ray equipment and its uses in discovering defects in metals. Mr. Williams' lecture was delivered in a very clear manner, and the interest in it was increased by the fine photographs that he cast on the screen. He had no difficulty in holding the attention of his listeners who would indeed have been willing to listen to him for a much longer time.

F. J. Connor.

Blue Chip

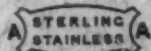
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No change in name in 25 years of good service, but
constantly improved by metallurgical progress

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The Tool and Die Steel of *broad adaptability*

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STEEL TREATERS' BALLOT

	YES	NO
1. Have you used salt baths for annealing, hardening, tempering?		
2. Have you discarded them because they break down and do not give consistent results?		
3. Do you know that <i>Lavite</i> is the only bath material that gives reproducible results, that does not break down with long usage nor cause decarbonizing? That gives uniform results in the shortest practical time, bringing forth a surface unchanged and free from scaling, pitting, oxidation or decarbonization?		
4. Do you want us to demonstrate <i>Lavite</i> on your work?		

If your answer is "yes" to number 4, fill in below and mail to the Bellis Heat Treating Company, Branford, Conn.

What kind and size of work do you want to try *Lavite* on?

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Individual ----- Address -----

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